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H.R. 1216—RENEWABLE ENERGY AND ENERGY EFFICIENCY TECHNOLOGY COMPETITIVENESS ACT OF 1989

HEARING

BEFORE THE

SUBCOMMITTEE ON
ENERGY RESEARCH AND DEVELOPMENT

OF THE

COMMITTEE ON
SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

ONE HUNDRED FIRST CONGRESS

FIRST SESSION

MAY 23, 1989

[No. 51]

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H.R. 1216—RENEWABLE ENERGY AND ENERGY EFFICIENCY TECHNOLOGY COMPETITIVENESS ACT OF 1989

TUESDAY, MAY 23, 1989

U.S. HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT,
Washington, D. C.

The Subcommittee met at 2:10 p.m. in Room 2325 of the Rayburn House Office Building, the Honorable Marilyn Lloyd, Chairman of the Subcommittee, presiding.

Present: Representatives Lloyd, Morrison, Smith of Texas, Fawell and Stallings.

Mrs. LLOYD. (presiding) Good afternoon, ladies and gentlemen.

Before we begin today, I do ask unanimous consent that the Subcommittee permit today's proceedings to be recorded by the media and others, and without objection, so ordered.

We are meeting today to receive testimony on H.R. 1216, the Renewable Energy and Energy Efficiency Technology Competitiveness Act of 1989. Congressman Morrison and I introduced the bill on March 1st, 1989 and were joined as original co-sponsors by Congressmen Sharp and Moorhead.

In the Department of Energy's FY 1990 budget submission we once again see the funding for renewable energy and energy conservation, research and development fall far below prior year levels. The request for renewable energy is a 23 percent reduction in energy conservation, is 53 percent below FY 1989 appropriated levels. The continuing decline in funding support has all but eliminated anything but a base R&D program.

I believe it is imperative that we change this downward course, and I hope that the passage of H.R. 1216 will provide a clear signal to the Department that we are seriously concerned about the lack of emphasis on the development of these technologies.

H.R. 1216 requires the Department of Energy to set technical performance goals for renewable technologies, provides for cost shared joint venture projects, authorizes funding levels on a multi-year basis to provide stability, and seeks to improve the competitiveness of U.S. industries by assisting the technologies into the marketplace.

In spite of low budgets, a government moratorium on federally funded demonstration projects, and concentration on high risk, long-term research and development, we can still point to successes when geothermal and solar technologies already contribute to our

energy supplies, with expected increases as we see improvements in efficiencies and economies.

Recent articles have focused on the success of the Luz technologies as a breakthrough for use of the supplemental utility power generation. Recent technological innovations using solar thermal technologies have allowed us to focus the sun's intensity to purify waste streams.

These developments are encouraging, but the problems extend beyond our shores. Recent data from the International Energy Agency indicates that energy consumption in the less developed countries is increasing at a higher rate than had been expected. Most of this increased energy supply has been provided by fossil fuels; namely, oil and coal. These nations need energy to support economic growth and development in order to rise above subsistence levels. We cannot deny that need, but we can provide viable options in solar and renewable energies, and we can provide new conservation technologies to ensure that the maximum benefits are achieved from the energy they use.

As we begin our Congressional debate about striking a balance between future energy needs and environmental concerns, I believe that increased use of renewable energy and energy efficiency technologies offers a prudent hedge against the possibility of the greenhouse effect and global warming.

Because of the lack of emissions of carbon dioxide and methane gases, two of the major players in the suspected global warming problem, these technologies will provide a safer environment no matter what the outcome of the global warming debate.

Before we begin, I do want to recognize the Honorable Sid Morrison, who is the Ranking Republican Member of the Subcommittee, for an opening statement.

Mr. MORRISON. Thank you, Madam Chairman. I have a formal statement, and I would ask that it be made a part of the record, and I would only comment that I appreciate your leadership in this issue area. We introduced the package last year. We learned from that process, and I think the bill we have in front of us today is second generation and it comes much closer to achieving the balance that we must find in this area.

[The prepared opening statement of Mr. Morrison follows:]

OPENING STATEMENT
HON. SID MORRISON
HEARING ON H.R. 1216, RENEWABLE ENERGY AND ENERGY
EFFICIENCY TECHNOLOGY COMPETITIVENESS ACT OF 1989
MAY 23, 1989

GOOD AFTERNOON. I AM PLEASED THAT THE SUBCOMMITTEE IS RECEIVING TESTIMONY ON THIS PROPOSED LEGISLATION. ALMOST A YEAR AGO WE HELD A HEARING ON THE PREVIOUS VERSION OF THIS BILL, AND I MUST SAY THE TESTIMONY IN THAT HEARING HAS PROVIDED SOME VALUABLE INPUT FOR DRAFTING THE BILL WHICH IS BEFORE US TODAY.

RENEWABLE ENERGY AND CONSERVATION R&D IS AN AREA IN WHICH THE INDUSTRY AND THE DEPARTMENT OF ENERGY HAVE VERY DIFFERENT VIEWS ON WHAT IT TAKES TO COMMERCIALIZE THE R&D PRODUCT, AND HOW SHOULD DEMONSTRATION PROJECTS BE CONDUCTED. BECAUSE THE RESEARCH COMMUNITY, INDUSTRY, AND DOE MUST WORK TOGETHER TO ACCOMPLISH THE GOAL OF COMMERCIALIZATION AND TECHNOLOGY COMPETITIVENESS, WE MUST STRIKE A BALANCE BETWEEN THE DIFFERENT VIEWS, SO THAT WE CAN MARCH AHEAD.

OVER THE LAST YEAR WE HAVE WORKED HARD TO ACHIEVE THIS BALANCE. I APPLAUD YOUR EFFORT, MADAM CHAIRMAN, AND I BELIEVE THE PROVISIONS IN H.R. 1216 CAN SERVE AS THE FRAMEWORK FOR CONGRESS AND THE ADMINISTRATION TO BUILD ACHIEVABLE GOALS AND MILESTONES TO ACHIEVE COMPETITIVENESS OF OUR RENEWABLE ENERGY AND CONSERVATION TECHNOLOGIES IN THE NEAR FUTURE.

Mrs. LLOYD. Gentlemen, your statements will also be made part of the record, and you may summarize as you wish, and our first witness is the Honorable John Berg, our Assistant Secretary for Conservation and Renewable Energy at the Department of Energy.

Dr. Berg, please proceed, and we apologize for the delay.

STATEMENT OF THE HONORABLE JOHN BERG, ASSISTANT SECRETARY FOR CONSERVATION AND RENEWABLE ENERGY, U.S. DEPARTMENT OF ENERGY; ACCOMPANIED BY MR. ALAN J. STREB, DEPUTY ASSISTANT SECRETARY FOR CONSERVATION

Dr. BERG. I am accompanied by the Deputy Assistant Secretary for Conservation, Mr. Alan Streb, on my right.

I appreciate this opportunity to appear before you today to provide our perspectives on the H.R. 1216, the Renewable Energy and Energy Efficiency Technology Competitiveness Act of 1989.

Over the past two decades, conservation and renewable energy has made vital contributions to our energy security, economic health, and quality of life. During this period, conservation has emerged as a major domestic and international resource, making major inroads into virtually every energy production in the demand sector, improving the efficiency with which all fuels are used, and providing powerful impetus to the expansion of the economy.

Meanwhile, renewable energy has become one of the fastest growing sectors in the energy marketplace, increasing its share of the domestic energy supply by some 30 percent in the past 20 years, and now supplying nearly 10 percent of current total domestic energy production.

The research sponsored by the Federal Government and private companies is now bearing fruit in better materials and improved components and systems designs, which will increase energy use efficiency and make alternative fuel use both reliable and economically attractive.

Madam Chairman, while much has been accomplished, neither conservation nor renewable energy has approached the full economic or technical potential, and properly focused federal efforts can help in sustaining and building upon past achievements and current practice.

While the Department does not support the bill as currently drafted, we do support its intent and can support many of its provisions. The Department in principle supports basic reauthorization of the conservation and renewable energy programs.

We believe that H.R. 1216 may provide an opportune and powerful vehicle to communicate to industry and the public the importance of conservation and renewable energy. H.R. 1216 would establish in legislation, national cost, performance, and commercial goals for some of the renewable energy technologies. The Department has developed conservation and renewable energy plans containing many of the goals identified in the legislation. We are currently in the process of updating these plans to reflect the R&D advances and current competitive conditions and to strengthen the linkage between R&D activities, future market opportunities, and

the Federal, State, and private sector strategies required to reach these goals.

With regard to Section 4 of the bill, we would therefore recommend that the committee provide more flexibility to the Department.

With regard to Section 6, on joint R&D ventures, the Department has initiated various collaborative research mechanisms as a vehicle for effective technology transfer. We believe that many of our efforts have been productive and in many instances innovative. We are prepared to support additional ventures of the type contemplated in Section 6 of the bill and agree that cost sharing must be a primary objective in successful collaborative efforts. We recommend more general language directing the Department to pursue joint ventures. We also believe that the advisory committee requirement should be reduced to a single committee with no more than two legislated subcommittees.

Regarding demonstration projects, we are fully aware of the interest that exists within the renewable energy industry and the Committee in the development of technologies at scale. However, the Department does not support the requirements in Section 6(e) for three demonstration projects. The cost effectiveness of demonstrations, particularly at a time of intense budgetary pressures, as compared to the payoff from research and technology development, is questionable.

I would like to point out that the Department will be reevaluating its policy concerning the proper scope of potential participation along the technology development continuum as a part of the internal reviews currently underway.

With regard to renewable energy exports, the Department recognizes the importance of international market opportunities to the renewable energy technologies. We believe that activities funded within the international line item are worthy of support. The Department of Commerce trade promotion activities and activities in support of CORECT have been productive to date and show that the public and private sector can effectively collaborate in exploiting foreign trade opportunities. We think that the requirement in H.R. 1216 to establish a public-private master plan for market share should be more properly emphasized—should more properly emphasize the level of exports since market share can be affected by a variety of uncontrollable circumstances.

And, finally, we recommend that the committee consider modifying or eliminating the requirement in Section 9 for a separate three-year strategic plan for energy technology. We think the committee will be pleased with the degree that strategic considerations are incorporated in future iterations of technology plans and the integrated national energy strategy, as reflected by the National Energy Policy Plan.

With a spirit of cooperation and shared objectives, I believe that we can work together to shape specific language which will be mutually supportable.

Madam Chairman, we want to thank the committee and work with the committee to achieve that objective.

We appreciate this opportunity to appear before you today and to gain your advice on these matters, and I would be happy to answer

any questions which you or the Subcommittee may have at this time.

Thank you.

[The prepared statement of Dr. Berg follows:]

STATEMENT OF

DR. JOHN R. BERG

ASSISTANT SECRETARY FOR CONSERVATION AND RENEWABLE ENERGY

U.S. DEPARTMENT OF ENERGY

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

U.S. HOUSE OF REPRESENTATIVES

MAY 23, 1989

Mr. Chairman and Distinguished Members of the Committee:

Thank you for the opportunity to appear before you today to share our perspectives with the Committee concerning H.R. 1216, the "Renewable Energy and Energy Efficiency Technology Competitiveness Act of 1989."

Energy efficiency and renewable energy are critical elements of our national energy resource. Secretary Watkins, in his first four months in office, has stated repeatedly his commitment to developing conservation and renewable energy as important components in the portfolio of energy technology which will be required to meet national economic, energy, and environmental objectives. We are moving as quickly as possible to translate that leadership into cogent and well articulated policies, programs, and strategies which will form the framework within which the Department, the Congress, State and local governments, and individual energy suppliers and consumers can all take appropriate action to meet our respective responsibilities.

The availability, cost, security, reliability, safety, and environmental impact of energy supply and use are fundamental to the strategic interests of the Nation. They affect our competitiveness, productivity, national security, and environmental quality. The Nation is not resource poor; sufficient domestic supplies of energy exist to meet our national needs for the foreseeable future - if we develop the technologies necessary to explore, capture, and exploit all of our resources economically and with minimal damage to the

environment to provide the fuels, heat, and electricity we need for future economic growth.

Over the past two decades, conservation and renewable energy have made vital contributions to our energy security, economic health, and quality of life. During this period conservation has emerged as a major domestic and international resource, making major inroads into virtually every energy production and demand sector, improving the efficiency with which all fuels are used, and providing powerful impetus to expansion of the domestic economy. Since the energy crises in the early seventies, the Nation has made great progress in reducing the amount of energy we use to produce a dollar of gross national product (GNP). GNP has grown about 40 percent while energy consumption has remained relatively constant.

Meanwhile, renewable energy has become one of the fastest growing sectors in the energy marketplace, increasing its share of the domestic energy supply mix by some 30 percent in the past 20 years, and now supplying nearly 10 percent of current total domestic production. Equally important, the private sector has made significant strides in introducing new high technology products into commercial use. However, neither conservation nor renewable energy has approached its full economic or technical potential, and properly focused Federal efforts can help in sustaining and building upon past achievements and current practice.

The Department and the Committee have long discussed many of these subjects, and I believe we are in general agreement on them. Beginning with today's hearing, we hope to move toward consensus in several additional areas through mutually supportable legislation based on H.R. 1216. While the Department does not support the bill as currently drafted, we do support its intent and can support many of its provisions. I would like at this time to share our perspectives on the specific provisions of the bill and offer some recommendations which we hope will lead to legislation acceptable to the Committee, the Department, and the conservation and renewable energy community.

The Department in principle supports a basic reauthorization of the conservation and renewable energy programs. We believe that H.R. 1216 may provide an opportune and powerful vehicle to communicate to industry and the public the importance of conservation and renewable energy; to reaffirm national commitment to sustaining the R&D necessary to realize their vast potential; to establish a multi-year funding and research strategy, to increase the participation of the private sector, both to facilitate technology transfer and to ensure that public funds are, in appropriate measure, focused on areas where the private sector believes that the greatest opportunities lie; and to authorize the Committee on Renewable Energy Commerce and Trade (CORECT) to pursue foreign market opportunities for renewable energy products and services to be provided by domestic firms. With a spirit of cooperation and shared objectives, I believe we can work together to shape specific language which will be mutually supportable.

H.R. 1216 would establish, in legislation, national cost, performance, and commercial goals for some of the renewable energy technologies. The Department has developed conservation and renewable energy plans containing many of the goals identified in the legislation. We are currently in the process of updating these plans to reflect R&D advances and current competitive conditions, and to strengthen the linkage between R&D activities, future market opportunities, and the Federal, State and private sector strategies required to reach these goals. We expect to cooperate with other Departmental elements to ensure that technology plans across the Department employ consistent economic and policy assumptions and that they serve as building blocks for an integrated national energy strategy.

With regard to Section 4 of the bill, we would therefore recommend that the Committee provide more flexibility to the Department. We share the view that technology plans should be developed with an appreciation for their marketplace significance; we recognize the importance of private sector participation; and we agree that the Department should continue to periodically transmit plans, or their updates, to the relevant Committees of Congress. Legislated cost and performance goals, on the other hand, would not allow us to adjust to changing conditions and markets. The Department had experience with National goals during the energy crisis of the 1970s. For example, by 1992 we were supposed to produce 2 million barrels of crude oil per day of synthetic fuel. It will not happen because markets and events moved in a different direction. That is why we

must provide flexibility to create a partnership with the private sector rather than legislating goals that cannot adjust to the changing market. In particular, the Department recommends that the Committee reevaluate the inclusion of market penetration targets within the legislation. Our past experience with such legislated goals indicates that they are soon outdated, that they often create rather than resolve uncertainty within the private sector, and that they are so dependent on factors outside the control of either the Department or industry that they do not provide a reasonable basis for program planning or accountability.

As stated earlier, the Department supports a basic re-authorization for the conservation and renewable energy programs. The Department also supports multi-year authorizations and has initiated a process to internally evaluate all energy programs, priorities, and strategies. The Department is also attempting to improve its multi-year programming and budgeting of resources. We are not today prepared to support the specific authorizations proposed in this bill. We are, however, prepared to commit to working together with the Committee as our internal initiatives yield results to shape a mutually supportable set of multi-year program authorizations. I am persuaded that with a continuing dialogue we can expect to arrive at mutually supportable time-frames and levels of authorization.

With regard to Section 6, concerning joint R&D ventures, the Department has initiated various collaborative research mechanisms as

a vehicle for effective technology transfer. We believe that many of our efforts have been productive and in many instances innovative. We are prepared to support additional ventures of the type contemplated within Section 6 of the bill, and agree that cost sharing must be a primary objective in successful collaborative efforts. However, the specificity of the legislative language would add an undesirable and unnecessary rigidity to the process. We recommend more general language directing the Department to pursue joint ventures within a basic authorization for conservation and renewable energy. The advisory committee requirement should be reduced to a single committee with no more than two legislated subcommittees.

The Department is fully aware of the interest that exists within the renewable energy industry and the Committee in seeking out common ground regarding development of technologies at scale. However, the Department does not support the requirements set forth in Section 6(e) that DOE specify in its FY 92 budget request three demonstration projects in sufficient detail to support the solicitation of bids. The cost-effectiveness of demonstrations, particularly at a time of intense budgetary pressures, as compared to the payoff from research and technology development is questionable. In general, commercialization activities such as large scale demonstration programs are most appropriately undertaken by the private sector, which is in the best position to assess the marketability of new technologies. Industry's willingness to invest in a new technology is frequently the best indicator of its near term market potential. In

addition, demonstration programs frequently require a disproportionate share of a very limited Federal budget, which could be better used to conduct higher risk research and technology development that might not otherwise be performed by industry. The Department will be reevaluating its policy concerning the proper scope of potential participation along the technology development continuum as part of the internal reviews currently underway. I should also note that considerable funds and staff resources would be required to comply with the Committee's direction as drafted. Diversion of such resources would constrain an already stringent research program and could prove counterproductive.

With regard to Section 7, concerning renewable energy exports, the Department recognizes the importance of international market opportunities to the renewable energy technologies. The Department believes that the activities funded within the International line item are worthy of support. The Department of Commerce trade promotion activities, and activities in support of CORECT, have been productive to date and show that the public and private sector can effectively collaborate in exploiting foreign trade opportunities. However, the requirement in H.R. 1216 to establish a public-private master plan for market share should more properly emphasize the level of exports since market share can be affected by a variety of uncontrollable circumstances. The Department would prefer to work with the Committee to shape a mutually supportable basic reauthorization of CORECT; to encourage the use of Federal, private, and laboratory expertise as

design or technical assistance to exploit targeted market opportunities; and to simplify administrative procedures for exports.

With regard to Section 8, the Department agrees that timely and accurate communication of program results and lessons learned on the benefits of conservation and renewable energy can provide valuable assistance to Federal agencies, while providing market opportunities for competitive renewable and energy efficiency technologies.

Finally, in keeping with my earlier remarks concerning the planning process currently being shaped within the Office of the Secretary, we recommend that the Committee consider modifying or eliminating the requirement in Section 9 for a separate three-year strategic plan for energy technology. We believe that the Committee will be pleased with the degree that strategic considerations are incorporated in future iterations of technology plans and the integrated national energy strategy, as reflected by the National Energy Policy Plan.

In conclusion, I wish to assure the Committee that the Department fully appreciates the strategic value of conservation and renewable energy, and, while we cannot support the bill as drafted, we believe that further discussions could lead to mutually supported legislation. We want to work with the Committee to achieve that objective.

Mr. Chairman, this concludes my prepared remarks. I appreciate the opportunity to appear here today, and I am prepared to address your questions at this time.

Mrs. LLOYD. Thank you very much, Mr. Secretary.

I am very pleased to note that Secretary Watkins has publicly indicated—has committed himself to the development of our renewables and conservation technology, but I was interested in knowing have we received any directives from the Secretary that indicate this change in emphasis from the previous Administration?

Dr. BERG. Yes, ma'am. I think there are several areas which I can specifically point to. We are working very diligently now and have redirected programs toward the area of eliminating chlorofluorocarbons. In the area of conservation we are working on a project right now—we are working with other departments in assessing both the energy and economic impacts that the CFC ban will have.

Secretary Watkins has made a very strong statement to everyone in the Department that conservation and renewables have a place at the table and will be a very important part as players, of the Department of Energy.

Mrs. LLOYD. You say in your testimony that you cannot provide the departmental recommendations for authorizations at this time. Which one of the authorizations do you disagree with at this time?

Dr. BERG. It may not be necessarily a question of disagreeing as much as ordering a priority—prioritizing the areas, and that is where we wish to again appeal to the committee that we work together and utilize the priorities as outlined by our plans, in which we have gotten specific input from industry and academia regarding our programs.

Mrs. LLOYD. One of the problems that we have had, of course, as you know, at the end of the '70s and the beginning of the '80s, we were pushing conservation and renewables with great gusto, and then we really see the demise of these programs, and it seems to me that if we are going to really maximize on our research and development dollars that we do have to move to the demonstration phase. We not only need to move to demonstration; we have to not be an adversary of the private sector but we do have to work with them.

Has the industry recommended any cost sharing, joint venture programs to you in this regard?

Dr. BERG. Yes, indeed. In fact, almost every one of our programs is a cost-shared program. We will start off, sometimes in areas where because of the lack of definition of a product area or the cost, the Department will start work, but shortly thereafter, as progress moves along and we are working with the private sector, they begin to see the potential of these technologies or we don't continue them. When they start seeing the potentials of the technologies, we then ask for cost sharing, and more often than not they are willing to provide it even before we ask them.

Mrs. LLOYD. As you know, one of the goals is to move the technologies out of the laboratory, and you asked for increased flexibility for inclusion of these technical abilities. If we don't have the goals and the milestones, how can we drive the technology?

Dr. BERG. We would really like to work with you on this. We would say that rather than legislating the goals and fixing them in stone that, rather, we work toward specific objectives and allow

those goals perhaps some fluctuation, because not always something that we start off on will bear fruit.

On the other hand, sometimes we are able to get there faster than what the original goal was, and by continuing to reiterate and look at where we are from year to year and analyzing it, we feel that we are able to set better goals than, for instance, setting them today and three or four or five years from now having them—

Mrs. LLOYD. I want you to understand where we are coming from. I think that we do need specific timetables for the completion of technology development if we are to maximize all our investment with the private sector.

Dr. BERG. Absolutely. I would agree with that. Not only that, but we should be looking at it as if—if it is not cost effective, that we discontinue that particular work.

But we would be more than happy to work with the committee in getting wording that we both can—

Mrs. LLOYD. Mr. Secretary, you said that it is most appropriate for the demonstration programs to be undertaken by the private sector. I would like to point out that the 5 billion clean coal technology bill was endorsed by the Department.

Do you have any reason to believe renewable/conservation technologies would not benefit by the same demonstration programs?

Dr. BERG. At some point when there is a potential for a good, solid breakthrough demonstration project that you are talking about, perhaps it is worthwhile.

However, with the budget constraints that we are under at the present time, we feel that rather than spending a lot of money in one demonstration program we can get more bang for the buck, if you wish, by working on joint venture projects, cost shared with industry in a variety of areas of research.

Mrs. LLOYD. Mr. Morrison.

Mr. MORRISON. Secretary Berg, you have commented on something that I think we all notice, and that is what appears to be a smoother working relationship on the joint venture basis; that is, working with associations or specific industries.

Any further comments on that?

I know there is a conflict here between the flexibility you would like to have and the goals that we might like to set just to make sure that something happens.

Are we getting where we need to go?

Dr. BERG. Congressman Morrison, I would say to you that in my tenure here at the Department of Energy that all of us that have been directing these programs are insisting that they show the benefit to the taxpayer and to the Congress that is providing us with tax dollars, and again I think that we have had various reviews. We have invited members of the staff, of the Committee staff, to attend these reviews, and I think that more of this must be done so that you people fully understand and appreciate both what we are doing and what we are going through and what the industry and people are saying about the programs.

I think, generally speaking, that no one in industry would take exception to our priorities. Granted, they may take exception with the amount of money we are spending on them.

Mr. MORRISON. You point out the shortcomings of the bill as far as you are concerned in several section areas, starting with Section 4 and going on through Section 9, but express a willingness to sit down and see what can be worked out.

Could we get started on that rather quickly?

Dr. BERG. Yes, sir. In fact, we have started working with the Senate staff already on this version. We would be more than pleased—

Mr. MORRISON. I am not sure that is the place to start, but—

Dr. BERG. They just happened to have it before you.

Mr. MORRISON. Then that is forgiven as long as we get the information first.

[Laughter.]

Dr. BERG. Sir, you will have it.

Mr. MORRISON. Thank you. No further questions.

Mrs. LLOYD. Mr. Fawell.

Mr. FAWELL. Thank you, Madam Chairman. I am sorry I was a bit late, and, Dr. Berg, I haven't had the opportunity of reading your statement. I caught just a bit of what you have said, and I guess rather than a question I would just comment that in regard to your comment where you said you would prefer not to have something carved in granite, or words to that effect, and allow you the flexibility, we certainly understand that.

I guess as one looks at the renewables and conservation budget—and you did say, too, people won't take exception to your priorities but to the money that you get to spend—and as I look at the money we are spending on civilian- oriented R&D in renewables and conservation, it is precipitously—it has precipitously dropped, and really the bill I think in proposed authorizations is relatively modest, just asking for some consistency as I see it and understand it, and I think anything that we can do to help in the alternative energy sources in this nation as we—with all deference to my dear friend from Texas, I have often commented that we just place so much emphasis on our burning of fossil fuels and so much evidence now of all of the harm that has been done to the spaceship earth, and so forth and so on, and to see relatively little movement.

And I don't mean to criticize you. The money factor is so darn frustrating. It seems to me that this bill is a step in the right direction, and, yes, it does force the Department perhaps to move more rigidly in certain areas, but at least we hopefully have some guarantee of some consistency.

I look at this bill, and I think it is a step in the right direction, just simply because it causes us to do what we know we have to do to push these alternative energy sources so we can have some breakthroughs in certainly renewables and conservation. I think it is vital that we do that.

So it is not a question, but a comment. If you have any comments to my comments, I would be more than glad to receive them.

Dr. BERG. I think your observation about consistency being needed is one that we would certainly agree with, and I think that consistency for any area where both the private sector can depend upon something going a certain direction for a given length of time would aid them as well, and so I do feel that consistency is there.

I am pleased to state, though, just as a little bit of follow-up on your comments regarding what we are doing, I think that the fruits of the program are showing up now in production automobiles. They are showing up in areas where—that you people who have been here on the committees have wanted that to happen. It may not have happened as rapidly as you would like to see it happen or that we might like to see it happen. But one has to understand that even today if we had a working ceramic engine, that it would be at least five years, right now—both General Motors—or one of the big three, General Motors, Ford, or Chrysler would say we go with it before it would actually be on the end of the production line coming off that end. But we are seeing ceramic parts in motors, not only here in this country but engines being produced overseas made with parts from companies that are producing them here in this country as a result of these programs.

So there is things that are happening there, and sometimes you might say it is maybe not happening as much or as fast as we would like to, but I do think that we are showing great progress.

Mr. FAWELL. Thank you. I have no more questions.

Mrs. LLOYD. Mr. Smith. And I ask unanimous consent that your opening remarks be made a part of the record.

Mr. SMITH. I was going to ask that, Madam Chairman. I don't have any other questions other than to ask for unanimous consent.

[The prepared opening statements of Messers. Fawell and Smith follow:]

THE HONORABLE HARRIS W. FAWELL

OPENING STATEMENT

May ~~MARCH~~ 23, 1989

SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT

HEARING ON RENEWABLE ENERGY AND ENERGY EFFICIENCY BILL

MADAM CHAIRMAN, I AM PLEASED TO HAVE THE OPPORTUNITY THIS AFTERNOON TO WELCOME OUR DISTINGUISHED GUESTS AND LISTENS TO THEIR THOUGHTS ON H.R. 1216, THE RENEWABLE ENERGY AND ENERGY EFFICIENCY TECHNOLOGY COMPETIVENESS ACT OF 1989.

THIS COMMITTEE RECOGNIZES THE IMPORTANCE OF STRIKING A BALANCE BETWEEN OUR ENVIRONMENTAL CONCERNS ABOUT ACID RAIN, OZONE DEPLETION, AND GLOBAL WARMING AND OUR FUTURE ENERGY NEEDS. I BELIEVE THAT THIS LEGISLATION HELPS STRIKE SUCH A BALANCE. BY STABILIZING RESEARCH AND DEVELOPMENT FUNDING LEVELS FOR RENEWABLE ENERGY AND ENERGY EFFICIENCY PROGRANMS, THIS LEGISLATION REAFFIRMS THE IMPORTANCE OF THESE PROGRAMS IN OUR NATIONAL ENERGY POLICY.

WHILE I RECOGNIZE THAT CONGRESS IS PRESENTLY UNDER SEVERE BUDGET CONSTRAINTS, I MUST POINT OUT THE IMPORTANCE OF INVESTING IN TECHNOLOGIES THAT ARE ESSENTIAL TO OUR FUTURE PROSPERITY AND WELL-BEING. IT IS TIME FOR US TO TAKE A SECOND LOOK AT ENERGY OPTIONS THAT MAY ALLOW OUR CHILDREN AND GRANDCHILDREN TO LIVE IN A CLEANER, SAFER ENVIRONMENT. WITH THAT SAID, I LOOK FORWARD TO HEARING FROM OUR GUESTS.

OPENING STATEMENT

REP. LAMAR SMITH

HEARING ON H.R. 1216, THE RENEWABLE ENERGY AND

ENERGY EFFICIENCY TECHNOLOGY COMPETITIVENESS ACT OF 1989

MAY 23, 1989

Thank you, Madame Chairman. I appreciate the effort that you and our Ranking Republican, Mr. Morrison, have put into this legislation, because it is clear that renewable energy and energy efficiency technologies have an important role to play in this nation's future energy mix. Solar and wind technologies are already making significant contributions in some parts of the country, and this subcommittee can be instrumental in providing additional goals and direction to the Energy Department in making these systems more efficient and economically viable.

Although I represent a District that is the heart of the nation's oil and gas industry, Texas is also a leader in emerging energy technologies. We have the academic support, entrepreneurial spirit, and abundance of sunshine that have made our state a major producer of solar technology. Texas A&M University is also a leader in research on using solar energy to produce clean-burning hydrogen fuel for future energy needs.

These are innovative and important research programs, and I look forward to hearing from today's witnesses. Thank you, Madame Chairman.

Mrs. LLOYD. Thank you very much.

We will be submitting additional questions to you in writing, and we would like for you to respond to for the record.

Thank you, gentlemen, for being with us today.

Dr. BERG. Thank you very much.

Mrs. LLOYD. We now welcome Panel 1, which includes Mr. Scott Sklar, Director, Solar Energy Industries Association, certainly no stranger to this Subcommittee; Mr. James Wolf, Executive Director, Alliance to Save Energy; Dr. Carel Otte, Geothermal Resources Association.

It is a real delight to have you with us today. Scott, I believe you are the lead witness on our panel today.

Mr. SKLAR. I appreciate that, Madam Chair.

Mrs. LLOYD. Since you are not bashful.

Mr. SKLAR. Yes, I never am.

STATEMENT OF MR. SCOTT SKLAR, DIRECTOR, SOLAR ENERGY INDUSTRIES ASSOCIATION

Mr. SKLAR. I would like to thank the committee for the opportunity to testify.

The Solar Energy Industries Association, which is the national trade organization of the photovoltaics and solar thermal manufacturers and component suppliers, strongly endorses H.R. 1216, the Renewable Energy and Energy Efficiency Technology Competitiveness Act of 1989. The legislation provides urgently needed direction and stability of the United States solar and renewable energy research and development efforts.

While U.S. energy policy has generally ignored solar energy development, our international competitors sensing a vacuum have steadily increased their solar energy research, development, and export assistance programs. And while the United States was the acknowledged leader of all solar technologies in the 1970's, we are gradually losing our technical edge due to an era of indifference and lack of foresight. Federal funding for solar programs dropped precipitously over the last eight years as the chart below shows:

DOE Program, FY '81, International, $12.0; FY '89, $1.0; OMB FY '90, $0.5; H.R. 1216, $2.5; photovoltaics, FY '81, $153.2; FY '89, $35.5; OMB FY '90, $25.0; H.R. 1216, $39.0; solar buildings, FY '81, $74.9; FY '89, $5.4; OMB FY '90, $4.2; H.R. 1216, $6.0; solar thermal, FY '81, $119.9, FY '89, $15.0; OMB FY '90, $13.0; H.R. 1216, $16.0.

The proposed legislation enhances programs, encourages greater industry/government cooperation, and establishes long-term goals essential to refocus the federal solar programs to maintain our worldwide technical leadership. These initiatives must pass before it is too late and our own industry is bypassed by the more ambitious efforts of our international competitors.

How ironic would it be for the United States to have to import the very technologies we developed and created. The legislation is the only answer to prevent VCR Syndrome, where the U.S. has spent hundreds of millions of dollars to develop solar technologies that are commercialized by our international competitors who will reap billions of dollars and millions of jobs. Our country needs to

position itself in the 21st century as a technological leader in technologies that are renewable, increase world productivity, and deter global climate change.

I would just like to submit my testimony for the record and really comment on Mr. Berg's testimony for you.

Mrs. LLOYD. Without objection, your entire written statement will be made a part of the record, and before we go any further I would like to ask unanimous consent that Representative Costello's opening statement also be made a part of the record.

So please proceed.

Mr. SKLAR. Thank you, Madam Chairman.

First of all, the goals and objectives of the bill are solid and sound. The fact is that the committee took very careful effort to consult with industry on the goals. The fact is that the goals mirror the standing U.S. Department of Energy five-year goals in place, and no one knows, including industry, any changes really in the goals that are set in the legislation.

So while I understand that most federal agencies are nervous about Congress mandating goals, it is frankly the very same goals that they have—have endorsed and worked with industry in the research and science community.

Therefore, I believe that the legislation is sound public policy. It is sensible and is reachable, and I would also say that Mr. Berg is correct, that the U.S. Department of Energy should be in a situation that if they can surpass the goals that Congress should be very proud and if they can't meet the goals that in hearings such as these you ask them and members of industry and the research community why not.

And it is true that sometimes we can't always meet goals, but I want you to know that these goals are solid and sound.

Second, authorization levels. The authorization levels that are proposed in this bill are very, very modest. Frankly, they bring us up to appropriation levels essentially of two years ago. They are not budget busters. They are really what is keeping a reliable program going, including inflation. This is no new increase. This is basic inflation proof to the program. Since most of these renewable energy programs are at closeout levels, what the legislation does is basically maintain them so that we have an honest and professional solar energy research effort.

You are to be commended for this. The Department must come to terms on authorization levels. As I testified before the subcommittee before, our problem is that we have not had authorization bills for many years and so that we have had problems in really maintaining our efforts in these programs and maintaining our industry commitment to them if the government indeed can't have a multi-year commitments to ours.

The third issue is cost shares. What was stated here is that the industry does cost share research. That is true. The problem has been that without level authorizations and these professed 30 percent cuts, for instance, in the photovoltaic budget, what we have is a situation in photovoltaics where the third year of an industry/government cost share on amorphous silicon technology. The most important final third year of joint venture is in question because OMB asked for a 30 percent cut. And the question is the industry

has already put up two years of their cost share. We are ready and they have worked their business plan to put up year three and the government is basically saying close it out.

Now, that is not a very, very honest relationship if we are cost sharing money.

Mrs. LLOYD. You say you were left dangling?

Mr. SKLAR. We are left dangling at the moment, very, very much dangling.

The worst program in this is the solar thermal power program. Here we have spent a decade developing concentrated dish engine technology, which right now can bring the cost of solar thermal power in very modular efforts to the utility grid. Cummins Engine, Westinghouse, and others have agreed to enter the cost share, and we understand DOE is backing out of its commitment, and these companies, most of which in the reflector side are in the great State of Texas, really need some support in making sure that these technologies are carried out to fruition or the United States will have lost the technology and the research and we will never commercialize it and we will watch the Japanese commercialize dish engine technology.

The next issue is demonstration, and your questions were very correct, Madam Chairman. Clean coal technology was endorsed by the Administration as a way to bring new technology to light. We don't need anything on such a grand scale at all, but there are places, particularly in the utility sector, where if the utility sector does not have some hands-on experience with this technology they will not buy it.

And so we are willing to contribute to these demonstrations, but we must have them there or you will not see the technology commercialized in that sector. And that is true for clean coal, and that has been true for the nuclear programs, and it is also true for the renewable and solar programs.

The international program is very, very important, and we do agree with the Department of Energy that in fact it not necessarily be only tied to market share, but other indices could be used to promote. But we want to point out that the international program has been successful because it is the first time that a federal agency board has been created to promote our exports, and 65 percent of our manufacturing capacity today is exports. It is the only market development program and must be kept and must be kept strong, and that is the group I will be testifying right after this today on that interagency group.

The three-year strategic plan is very, very important, and although again federal agencies don't like to be coerced in doing these things. The fact is because the solar renewable programs have been the little, small kids on the block we have not had the kind of detailed view by senior agency officials on where we ought to go and what their plans are to commercialize the technology.

The Japanese have done it, the Germans have done it with their governments, even India, and we need to get on—you know, really get off our chairs and start being participants here, and this is a way that you can nudge the agency to help us export and commercialize our technology domestically.

My final point to you on the DOE program as a whole. Our sense from industry is that the Administration and the managers are looking on us more kindly and gently from a program sense. We are still very, very unhappy with the OMB request, particularly, I believe, in both photovoltaics and solar thermal and solar buildings, to close out our effort, and I have been very blunt that we are at the bottom we can go or we will not produce anything other than keep some laboratories going. And the fact is that the Department of Energy now is looking at reorganizing its programs and in fact dropping some of these renewable energy technologies if authorization bills and their appropriation bills following do not come up to snuff.

We are very nervous about that. We do not know the details of it, obviously, but the issue is what you have done here is very important. It sets a refocusing of the program. It deserves a lot of support, and our industry thanks you very deeply for it.

Mrs. LLOYD. Thank you very much, Mr. Sklar.

Mr. SKLAR. I also have to apologize, but I do have to leave in about 10 minutes to testify in the Committee on Renewable Energy Commerce and Trade.

Mrs. LLOYD. If the other witnesses don't have any problems with our asking a few questions, we would appreciate it.

Mr. Morrison, questions?

Mr. MORRISON. Scott, you have taken a very strong position of mandating goals. I guess from your experience you are saying that if we don't do that we are just not going to get there. We are not going to—the flexibility that the Department asks for allows them to deviate from the directions we just have to pursue.

Mr. SKLAR. Well, let me put it this way. I think the first bargaining chip is that the goals you have recommended are consistent with what they have said over the years and what industry has said over the years. So what is the big deal?

But obviously, if the goals are going to hold up an authorization bill that we think is essential, I mean it is probably worth having an authorization bill. But the principle is correct, and I just wanted to assure the subcommittee that the language that you have in there is real, that the fact is that you don't have punitive measures if you don't meet the goals, and as long as you don't have that I think everybody can live with it.

But the goals are—we have worked with you on that. We have worked with DOE on that. They are solid.

Mr. MORRISON. I am fairly confident we will include them in some form.

Thank you. No other questions.

Mrs. LLOYD. Mr. Fawell.

Mr. FAWELL. The only question I have is—I guess shock isn't the right word because it isn't that, but when you talk about the solar thermal and the solar buildings and in photovoltaics, also, the effect is a breach by the DOE in regard to a contractual relationship they have with these various entities to supply matching funds?

Mr. SKLAR. Well, technically—legally, probably not because all agreements are based on whether monies are provided by the Congress. So you can get out of that. But we are a small business in-

dustry. I am the solar lobbyist for the industry, and that is it, and—

Mr. FAWELL. The money has been put—

Mr. SKLAR. The money on the industry side has been put up for the last couple of years in both solar thermal and photovoltaic, and DOE has met it and it has been a very collaborative program. The issue is again when you—the third year, when you are supposed to really start commercializing this technology and show it is for real, to have concerns about that it ain't going to be there puts us in the situation of, "what do you do?"

And, yes, maybe a company or two of the partnerships can find money outside, but the fact of the matter is we have spent, since the Arab oil embargo in 1973, 15 years to finally commercialize the technology, and you have seen some examples, the Luz engineering plants in Southern California, $150 million photovoltaic industry that was not here 15 years ago.

So we are in the marketplace. Small, but we are getting there.

The issue is that it would be a waste of 15 years, though, if you don't—if we just don't be consistent here and get this technology out so that we create jobs and make money from it.

DOE will not do this, and of course OMB will not do it without Congressional prodding. I do not believe the problem is with DOE any more. I believe our problems are at OMB.

So we have had a change from the senior DOE political people saying renewables are important, solar is important, and I think—we believe that. The issue is that OMB now is saying, yes, but we have some other programs that are high priority at DOE, and that is our problem.

[The prepared statement of Mr. Sklar follows:]

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TESTIMONY

by

SCOTT SKLAR
EXECUTIVE DIRECTOR
SOLAR ENERGY INDUSTRIES ASSOCIATION

before

HOUSE SCIENCE SPACE TECHNOLOGY COMMITTEE
SUBCOMMITTEE ON ENERGY RESERACH & DEVELOPMENT
HEARING ON THE RENEWABLE ENERGY AND
ENERGY EFFICIENCY TECHNOLOGY
COMPETITIVENESS ACT OF 1989 (H.R 1216)

MAY 23, 1989
WASHINGTON, D.C.

INTRODUCTION

The Solar Energy Industries Association (SEIA), the national trade organization of the photovoltaics and solar thermal manufacturers and component suppliers, strongly endorses, H.R. 1216, the Renewable Energy & Energy Efficiency Technology Competitiveness Act of 1989. The legislation provides urgently needed direction and stability of the United States solar and renewable energy research and development efforts.

While U.S. energy policy has generally ignored solar energy development, our international competitors sensing a vacuum have steadily increased their solar energy research, development, and export assistance programs. And while the United States was the acknowldged leader of all solar technologies in the 1970's, we are gradually losing our technical edge due to an era of indifference and lack of foresight. federal funding for solar programs dropped precipitously over the last eight years as the chart below shows:

DOE PROGRAM	FY'81	FY'89	OMB-FY'90	H.R.1216
INTERNATIONAL	$12.0	$1.0	$0.5	$2.5
PHOTOVOLTAICS	$153.2	$35.5	$25.0	$39.0
SOLAR BLDGS	$74.9	$5.4	$4.2	$6.0
SOLAR THERMAL	$119.9	$15.0	$13.0	$16.0

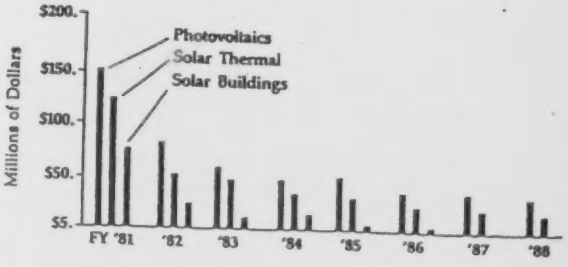
The proposed legislation H.R. 1216 enhances the programs, encourages greater industry/government cooperation, and establishes long term goals essential to refocus the federal solar programs to maintain our worldwide technical leadership. These initiatives must pass before it is too late and our industry is bypassed by the more ambitious efforts of our international competitors.

How ironic would it be for the United States to have to import the very technologies we developed and created. The legislation is the only answer to prevent VCR Syndrome, where the U.S. has spent hundreds of millions of dollars to develop solar technologies that are commercialized by our international competitors who will reap billions of dollars and millions of jobs. Our country needs to position itself in the 21st century as a technological leader in technologies that are renewable, increase world productivity, and deter glocal climate change.

The years of 1989/1990 will determine whether the United States will have a domestic solar energy industry or relinquish its technological leadership to our international competitors. Our country faces the real possibility of importing solar technologies in the years when they become fully cost-competitive. From my point-of-view, the United States lacks an effective energy policy and has biased priorities against maintaining our technical predominance and development of solar and renewable energy technologies. This bias is exemplified by the Administration's request to cut the $352 civilian nuclear energy research budget by only $2 million in FY'90 in contrast to their request to cut the aggregated solar budgets of $56.9 million by $13.2 million.

At some point, the U.S. Congress must come to terms as to whether you want to maintain a United States solar energy research effort. The U.S. Congress must also come to terms that at some level, lower solar budgets will not be effective in furthering the technology. The Solar Energy Industries Association, the national trade organization of the photovoltaic and solar thermal manufacturers & component suppliers, believes that the FY'89 funding levels are that bottom line. Therefore, the U.S. solar energy industry asks this Committee to hold the line, maintain an effective U.S. solar energy effort, and come to grips with the reality that if the United States does not push the technology out of the research pipeline, our international competitors will, and the United States will be totally reliant on our competitors for solar technologies for generations to come. Congressional actions in these two years will determine the outcome since the Administration has shown a "business as usual" approach.

Trends in Federal Solar R&D FY '81 - FY '88

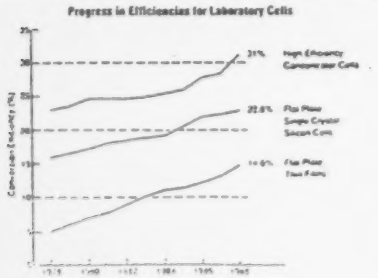


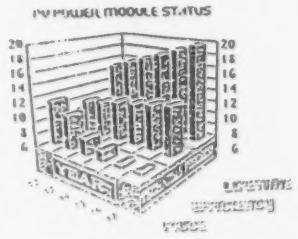
PHOTOVOLTAICS

The United States photovoltaics program has three basic thrusts: Bring down the costs of the technology through increased efficiency through the development of new materials and processes in manufacturing photovoltaic cells; Assist the industry in cost-shared research to commercialize research developments; and provide design assistance & review for large-scale photovoltaic systems for export, and government & utility procurement.

As you can see in the addenda, the photovoltiacs program has made great strides with over twenty world efficiency records of photovoltaic cells and modules. The chart below summarizes the cost reductions and the increases in lifetime & efficiency over the last six years as a result of the research program. The United States has maintained our technological lead worldwide due directly these research efforts. However, while the U.S. photovoltaic marketshare has been maintained through level funding during the FY'88-89 years, the precipitous cuts recommended by the White House (30%) will undercut the U.S. industry so badly that it is very unlikely the industry would ever recover. I cannot emphasize enough to this Subcommittee, that whatever the Congress decides has profound effect on the private investment markets. When Congress maintained level photovoltaic research monies in FY'89, increased private capital flowed to our industry. If Congress cuts this small research program, the private markets will sense that the United States government lacks the resolve to commercialize photovoltaic technology, and disinvestment will occur. Program cuts will insure that the United States will lose both our technological and market leads to both Germany and Japan.

The U.S. Department of Energy Photovoltaic Program has been effectively managed, and has developed an excellent relationship with the private sector. The national laboratory and university efforts are effectively integrated into the research program. This R&D program is a model on how best to commercialize high-technology. Funding for FY'90 should be increased to $40 million or at least maintained at the current $35.5 million level.





SOLAR BUILDINGS

The U.S. Department of Energy Solar Buildings Program is the smallest of the research and development programs and has been essentially at a closedown level of $5.4 million over the last few years. While buildings consume nearly 35 percent of U.S. energy and produce more greenhouse gases than the U.S. utility sector, this energy research area receives the least support. While the United States sits idly by, our international competitors in Scandanavia and Japan have geared up to commercialize energy efficiency technologies which have already begun to enter the United States market.

The solar building research effort has centered on three basic research areas: Solar cooling research using desiccant cooling technologies and new polymers in desiccants which can absorb up to 2000 percent of their own weight, efficiently dehumidify air thus providing cost-effective space cooling. The result of this research will save consumers millions of dollars for space cooling as well as saving utilities from building costly power plants to meet daytime cooling demands.

The second research area focusses on both passive and active solar design assistance. The Solar Energy Research Institute has worked with industry to develop a computerized energy simulation program for seven building types in two climate zones. This computer program will help builders select cost-effective passive solar applications in our nation's buildings. Under US/DOE auspices, SEIA and ASHRAE have developed a commercial-scale solar water heating design manual based on our experience over a decade with solar systems on federal and commercial buildings. In 1989, SEIA/DOE will develop and publish companion installation and operations/maintainance manuals for these large-scale systems. The final program thrust involves research on electrochromic or "smart" windows. By deposing an transparant metal-oxide material on glass, cooling costs for both buildings and automobiles may be significantly lowered. This technology along with photochromic glass has useful potential in the active solar industry in making collector glazings more efficient.

The potential markets for energy efficient technologies are extraordinary. But again, if the United States does not have the interest to commercialize these technologies, our competitors will. Does the United States have the resolve to follow-through on its research? Only the U.S. Congress can answer this question.

SOLAR THERMAL POWER

The United States now has 200 megawatts of completely private sector financed solar-steam-to-electricity utility-grade power plants. The solar trough concentrators used derive directly from US/DOE-sponsored research. This glass technology will soon be superceded by US/DOE developed stretched membrane technology utilizing a silver-coated polymer. The polymers will reduce the cost of this technology even further. Utilities are utilizing solar thermal technology for peak-power applications because they produce the most power during the utility's greatest demand for electricity (noontime), and they have minimal regulatory obstacles due to their cleanliness (no polluting emissions) and surety of supply (sunlight) that they can be constructed within fifteen months.

The U.S. Department of Energy Solar Thermal Power Program has three major program thrusts. First, the program will finish the upgrading of stretched membrane dishes and heliostats to efficiently concentrate sunlight. Actual trial tests are necessary to assess research progress and permit fine tuning. Secondly, second generation work to develop working solar dish concentrators which focus sunlight on engines that are capable of running electric generators, is being pursued through industry joint ventures. Finally, technology spin-offs to power lasers and detoxify wastes will be aggresively pursued as a new cost-effective high value market for these technologies.

The solar thermal technologies are also being commercialized by our industrial competitors. The European Consortium, Phoebus, plans to build a 30 megawatt solar central receiver tower in Jordon using stretched membrane heliostats. Such a venture by European governments may thrust European industries as the major commercializers worldwide of this technology.

The Solar Thermal Power Program should be funded at the $20 million level in FY'90 to remain competitive. A minimum of $17.5 million is necessary just to maintain ongoing programs. Cuts to $13 million as proposed by the Administration would effectively cut out the U.S. industry from federal research efforts and just support limited laboratory work that may never be commercialized. Price breakthroughs, so far, have been very promising as shown in the charts in the addenda taken from the August 1988 Report to Congress titled, "Bringing Solar Thermal Technology to the Marketplace".

Solar thermal power technologies have shown that they are competitive in the peak power utility markets today. New advances in technology will make them even more competitive. The world markets offer a virtually unlimited opportunity to successfully commercialize these technologies. Solar thermal power offers a competitive way not only to produce electric power but detoxify hazardous wastes, accomplished successfully by Sandia National Laboratories in 1988. Successfull experiments by the Solar Energy Research Institute in 1988 which concentrated sunlight 60,000 times, enough to power lasers, is a breakthrough important to pursue.

The Solar Thermal Power Program has an effective working relationship between the primary national laboratories, the Solar Energy Research Institute (SERI), Sandia National Laboratories, and the U.S. solar thermal industry. The research program deserves higher consideration by the Congress as an important element of federal research.

INTERNATIONAL

The international line item of the U.S. Department of Energy supports multiagency activities mandated under P.L. 97-370 which created the federal interagency board, The Committee on Renewable Energy Commerce and Trade (CORECT) to coordinate federal efforts to promote solar & renewable energy exports. This small $1 million program leverages more money than any renewable energy program in the U.S. Department of Energy Conservation & Renewable Energy program.

Aside from a series of trade missions and education materials, the program is supporting a conference and trade show in May 1989 to promote U.S. renewable energy technology & services in the Caribbean Basin & Latin America. The program coordinated by the U.S. renewable energy trade association umbrella group, the U.S. Export Council for Renewable Energy (US/ECRE), is the first of a series of market sector promotion program geared to meet increasing international competition from our international competitors.

The $1 million program should be increased to $2.5 million rather than cut to $0.5 million as recommended by the Administration. For the last eight years, the United States renewable energy effort was focussed, wrongly, on long-term, high risk, research & development. This small program is the only short term government effort to meet our competition head-on. The international program ought to be preserved and enhanced.

CONCLUSION

The United States solar energy research and development program hs been an outstanding success even through disinterest, budget cuts, and low energy prices. Solar water heating technologies are fully integrated into the marketplace with some utilities instituting incentive programs for peak load shaving. Over 200 megawatts of solar thermal power technologies provide utility-grade electricity for over 150,000 homes with new generations of technology that will be lower cost. Photovoltaic costs have come down ten fold in a decade and the program has had over twenty efficiency records in 1988 alone! As research increases, solar energy costs will be lowered and market penetration will significantly increase.

Solar energy technologies can reduce greenhouse gas emissions significantly by over 30 percent in the building sector which which accounts for 35 percent of our energy, by over 20 percent in the utility sectory for peak power and in some instances baseload generation which account for 25 percent of our energy, and for remote power applications which account for 5 percent of U.S. energy use and over 50 percent of Third World energy use.

The authorizations in H.R. 1216 are appropriate in that they turn support around to redevelop our national solar energy effort. Multiyear authorizations are absolutely essential for industry to plan and add stability for program development and planning. In addition increases in funding will in turn add confidence to the private capital markets attracting further investment in the U.S. solar energy industries. While the goals are more ambitious than the funding levels, it is important that the bill be pragmatic to insure passage, and I urge the Subcommittee to stick with the numbers and push for passage in 1989. I caution the Subcommittee that failure to do so will cause an irreversable chain of events that will cause private investment to dissipate and foreign competitors to control the world markets and ultimately our own.

Joint ventures are an essential component to this legislation and have been shown as effective by our international competitors particularly in Germany and Japan. However, the Congress must be aware that the U.S. solar energy industry is a very young and small industry. The vast majority of solar companies are less than fifteen years old and are small businesses. Therefore, industry contributions should not only include financial contributions but in-kind contributions in land, labor, licensing and comparable investments.

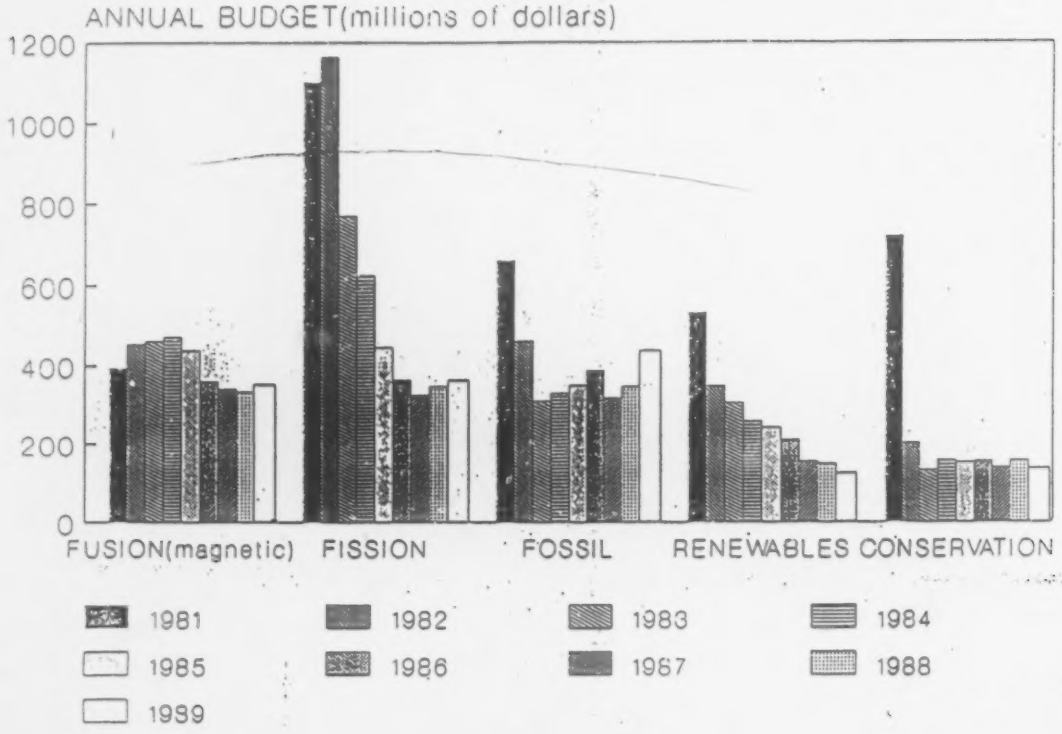
Solar joint ventures are applicable in manufacturing passive solar and solar water heating equipment and products, photovoltaic manufacturing and project development, and solar thermal power utility and industrial process heat applications and projects. The federal government as a partner, facilitator, and promoter is critical if our industries are to compete internationally. However such joint ventures should be industry generated and not government mandated or controlled. Joint venture development is best initiated by the U.S. industry and especially by those companies solely dedicated to solar energy development.

The Solar Energy Industries Association (SEIA) commends the Subcommittee for its leadership in the development of solar energy research, development, and commercialization. The Renewable Energy and Energy Efficiency and Energy Efficiency Technology Competitiveness Act of 1989 (H.R. 1216) is sound public policy in the nick of time. The legislation deserves bipartisan support and quick passage. For our industries' sake and that of our country's and the world's energy, economic, employment, and environmental security -- solar energy development must be developed expeditiously.

The proposed legislation H.R. 1216 enhances the programs, encourages greater industry/government cooperation, and establishes long term goals essential to refocus the federal solar programs to maintain our worldwide technical leadership. These initiatives must pass before it is too late and our industry is bypassed by the more ambitious efforts of our international competitors.

How ironic would it be for the United States to have to import the very technologies we developed and created. The legislation is the only answer to prevent VCR Syndrome, where the U.S. has spent hundreds of millions of dollars to develop solar technologies that are commercialized by our international competitors who will reap billions of dollars and millions of jobs. Our country needs to position itself in the 21st century as a technological leader in technologies that are renewable, increase world productivity, and deter glocal climate change.

ANNUAL APPROPRIATIONS OF DOE CIVILIAN R&D PROGRAMS (current dollars)



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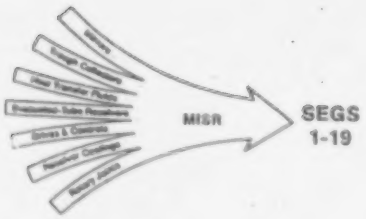
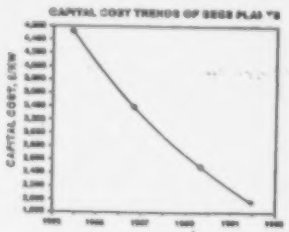
SOLAR THERMAL RESEARCH & DEVELOPMENT

As illustrated below, innovations in materials and components for parabolic troughs were integrated into and proven by the DOE Modular Industrial Solar Retrofit (MISR) systems. These enabling technologies encouraged Luz to employ these component improvements in its commercial systems. As innovations were incorporated into successive commercial systems, each new generation reflected lower system capital costs and lower energy production costs as illustrated. Luz is now considering further reductions in cost by replacing hybrid solar/gas steam generators with storage systems currently under development by DOE. Specific feedback of this kind is incorporated into the DOE research and development program and strengthens industry's ability to continue deployment of systems in broader applications with increased user confidence.

Commercial Solar Thermal Systems

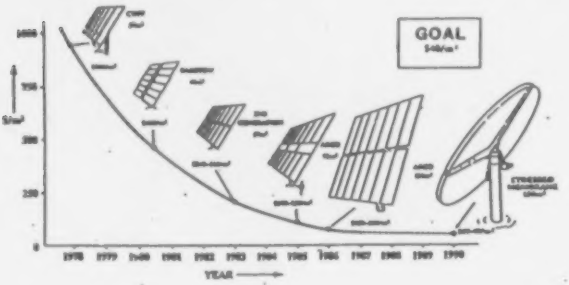




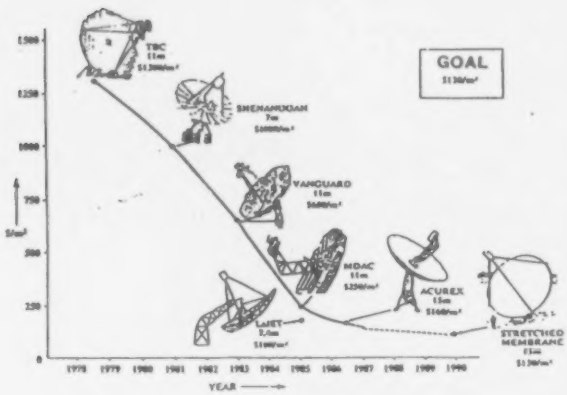
Such processes, in the longer term, also allow solar thermal systems to enter advanced applications such as hazardous waste destruction, materials processing and fuels and chemicals processing. While prototype solar thermal systems have not been tested in these applications, industrial manufacturers of concentrators have begun to see how the low-cost membrane dish concentrators and central receiver technology can directly be used to conduct chemical reactions in a receiver/reactor. Laboratory data have encouraged industry to begin to develop plans and assess the market potential for integrating solar thermal systems into these emerging applications which have national importance.

Receivers for solar thermal systems have also evolved during the past decade. Initially small-scale field experiments were needed to investigate the feasibility of using tube receivers to produce steam. In the early 1980s a scaled-up water/steam receiver was deployed in the 10-megawatt Solar One Pilot Plant, a systems experiment developed by DOE in conjunction with Southern California Edison Utility Company. Today's R&D efforts are aimed at further reducing receiver costs through the use of advanced designs and molten salts as the heat transfer fluid.

Progress In Heliostat R&D



Progress In Dish Collector R&D



Selected New Records Set by Program-Related Research During 1988

Achievement	Old Record	New Record	Who Set It
Conversion efficiency for a small a-Si three-junction cell (0.25 cm^2)		13.3%	Energy Conversion Devices
Conversion efficiency for a two-junction a-SiC/a-SiGe submodule (900 cm^2)		6.3%	Solarex
Conversion efficiency for a large single-junction a-Si module (2900 cm^2)	5.5%	6.7%	Chronar
Largest commercial [illegible] in operation			[illegible] Corporation
[illegible]		14.6%	ARCO Solar
[illegible]		11.1%	ARCO Solar
[illegible]			[illegible]
[illegible]			[illegible]
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[illegible]			[illegible]
[illegible]		19.3%	SERI
[illegible]		24.7%	Varian Associates
[illegible]		22.7%	Varian Associates and ENTECH Corp.
[illegible]		31.0%	Stanford University
[illegible]			Stanford
[illegible] concentrator (100X)		28.8%	Stanford
Conversion efficiency of module-ready high-resistivity Si concentrator cell (150X)	22%	25.3%	Stanford
Conversion efficiency of module-ready, low-resistivity Si concentrator cell (100X)	23.5%	24.2%	University of New South Wales
Diameter of crystalline silicon material having long minority carrier lifetime (21 milliseconds)	20 mm	52 mm	SERI

Progress in Research - 1988

Fundamental and Supporting Research

- Achieved 19% efficiency for AlGaAs cells through cooperative project (Kopin, Research Triangle Institute, SERI)
- Created mathematical model to explain loss mechanisms in CIS and CdTe cells, revealing areas for efficiency improvements (Colorado State University)
- Performed more than 8000 material/cell/module tests and measurements for more than 100 different organizations (SERI)
- Developed spectroscopic scanning tunneling microscope method for the direct imaging of atoms in electronic solids (SERI)
- Optimized a method to measure microvoids in good-quality amorphous silicon, to help manufacturers improve photostability (SERI)
- Grew high-quality gallium phosphide on silicon with greatly reduced defect density (SERI)
- Predicted theoretically that novel semiconductor compounds can be stabilized epitaxially, and may be useful as new photovoltaic materials (SERI)
- Initiated a cooperative effort to study single-crystal silicon (SERI, Institute of Energy Conversion, ARCO Solar)
- Improved [illegible] measurement accuracy [illegible] (Sandia, SERI)
- Performed Atmospheric Optical Calibration [illegible] measurements, and data reduction characteristics (SERI)

Thin Film/Thin Films

- Quadrupled [illegible] and doubled thin film [illegible]
- Conducted [illegible] comprehensive [illegible]

Crystalline Silicon

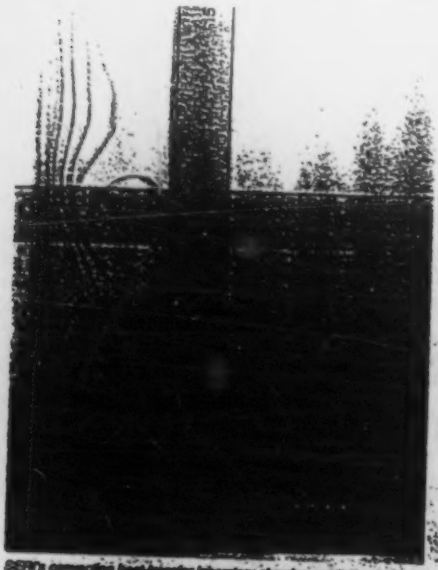
Modules/Encapsulants

Systems/Subsystems

- Planned, designed, and installed systems (Sandia)
- Developed and published Photovoltaics for Military Applications, and received DOD/industry/users (Sandia)
- Continued work on Guatemala vaccine refrigeration project and advised UNICEF, USAID, Pan American Health Organization, and others on PV projects (Sandia)
- Completed development of advanced power conditioning unit, with more than 95% dc-to-ac conversion efficiency and cost projections of $0.06 per watt (Sandia)
- Performed detailed electrical analysis of fielded systems; developed substantial changes to PV section of National Electrical Code (Sandia)

Applications Experiments

- Awarded contracts for four Emerging Technology modules for PVUSA; installed data acquisition system; constructed instrumentation building (PG&E, DOE, Sandia, SERI)



SERI's convection heat-transfer laboratory showing ventilation jet in an indoor air quality test cell

Solar Energy Research Institute

Low-Temperature Heat and Mass Transfer Laboratory

Contact: Desikan Bharathan, Thermal Systems Research Branch

The laboratory is used to study and improve methods of transferring heat and mass under the small driving forces that often exist when the sun is the energy source. The driving force can be a temperature gradient or other intensive thermodynamic differential, such as a concentration gradient.

The current laboratory setup includes an enclosed test cell that can be operated at pressures ranging from two atmospheres to low vacuum. Warm and cold water circulate through the test cell, allowing efficient heat and mass transfer with a variety of exchangers. The test cell is fully instrumented to measure all process variables and is automated to efficiently acquire data.

The laboratory can be readily adapted to study and test other low-temperature heat and mass transfer processes, especially in advanced gas–liquid devices. Processes studied and tested include vacuum drying, material degradation caused by outgassing in vacuum environments, gas sorption and desorption from liquids, and other continuous and staged separation processes.

Desiccant Dehumidifiers

Solar Energy Research Institute

Solar Desiccant Cooling Laboratory

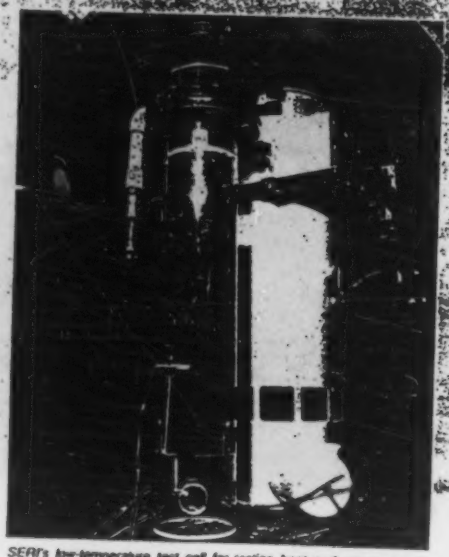
Contact: Ahmad Pesaran, Buildings Research Branch

The laboratory houses three facilities used to test materials, geometries, and components for desiccant dehumidifiers: sorption, single blow, and cyclic. All three provide controlled and conditioned process and regeneration air to test desiccant cooling systems.

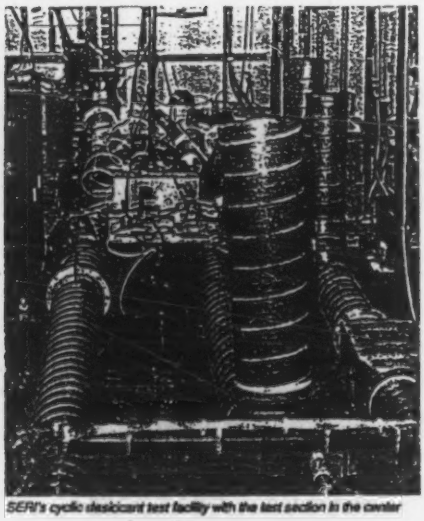
The sorption test facility measures the water equilibrium capacity and mass transfer rate of solid desiccant materials under isothermal conditions. These materials are exposed to process or regeneration air flow to attain dynamic equilibrium under a specific geometry.

The single-blow test facility generates data on transient heat and mass transfer and pressure drop for small-scale dehumidifiers with promising material and geometry combinations under adiabatic conditions. The momentum and heat and mass transfer characteristics can be measured to test the performance of different combinations of geometry and material.

The cyclic test facility is used to test advanced prototype desiccant dehumidifier components, such as



SERI's low-temperature test cell for testing heat and mass transfer showing direct-contact condensers



SERI's cyclic desiccant test facility with the test section in the center

a spirally wound wheel using silica gel with parallel-passage air flow. The test facility measures the performance of dehumidifier wheels under cyclic operation as a function of rotational speed, inlet air temperature and humidity, and air flow rates of both process and regeneration airstreams.

Apertures and Windows

Florida Solar Energy Center

Fenestration Research Facilities

Contact: Ross McCluney, Research and Development Division

Facilities and equipment for fenestration research include daylight availability measuring stations, a skylight testing station, a fast-response multichannel photometer, and solar calorimeters.

The daylight availability stations consist of instruments to measure and a computerized data acquisition system to analyze daylight. The Skylight Testing Station is used to test the optical properties of skylights and skylight wells. It is also used to calibrate light sensors and daylight measurements inside scale models of buildings.

The fast-response multichannel photometer can make rapid and repeated measurements of illuminance at eight locations by placing miniature light sensors inside small or full-scale models of buildings. The instrument is controlled by a computerized data acquisition system. The solar calorimeters measure the relative solar radiant heat gains through two different fenestration systems in simultaneous, side-by-side, outdoor tests in full sunlight.

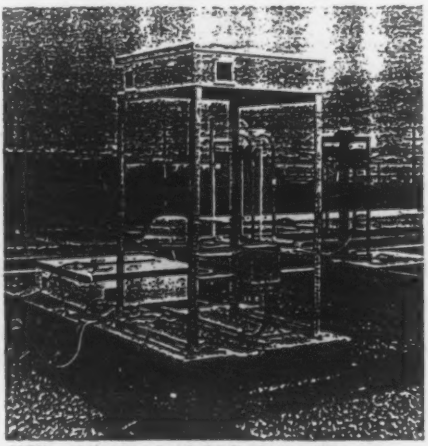
Lawrence Berkeley Laboratory

Solar-Optical Properties Laboratory

Contact: Stephen Selkowitz, Applied Science Division

The group has advanced facilities to conduct research on the optical and thermal properties of fenestration systems, shading systems, and building envelope systems. A large integrating sphere can measure the hemispherical transmittance of materials, components, and systems as a function of sun and sky conditions. The sphere can measure visible or solar transmittance for samples up to 2 ft by 2 ft. Typical uses for the integrater include measuring transmittance properties of skylight light wells; light guides; complex diffusing glazings with angle-dependent properties; and complex shading systems such as venetian blinds, fins, and honeycombs.

A luminance and radiance scanner for measuring bidirectional transmittance and reflectance of materials, components, and systems is also available for sample sizes up to 2 ft by 2 ft. The instrument measures the directional properties of visible (or radiant) flux transmitted (or reflected) through shading devices within 2-sr directions of emittance for any possible direction of uniform directional incident flux.



FSEC's model used to collect daylight illuminance measurements

Mrs. LLOYD. Thank you very much.

So many of the companies that make up your organization are small business people, very small.

Mr. SKLAR. Indeed.

Mrs. LLOYD. What level of cost sharing would you recommend would be practical and workable?

Mr. SKLAR. In my testimony I outline that it should be in three different kinds. One obviously is cold, hard cash, somewhere between 20 to 50 percent, and that is for the larger side of the industry.

Some of it I think ought to be allowed as—for the companies to leverage state participation, and we have been very successful in that. For instance, we have 3M Corporation, Entech, and Austin Power & Light putting in a project in Texas, one of the three largest photovoltaic concentration projects. They have private, federal, state, local money. They ought to encourage the private sector, if they cannot ante up all the money themselves to look for other partners.

And I think that we have proven that we can do it, and that is my concern. It is not really how much, but what is considered as part of the ante in the cost share.

Mrs. LLOYD. Here again we are approaching the phase where we have to decide what is an investment and what is an expenditure, and it seems to me if we can develop these technologies and get them to the marketplace instead of the Pacific commercializing the project, this indeed is an investment in our future which has a great potential for payoff.

Mr. SKLAR. I agree, and it is important to kick the tires. Our industry will not buy solar technologies unless they see it is real, as you would not buy a car out of a catalog. You will buy it when you see it and you have seen reports about it and your neighbor buys it, and the fact is that unless we are able to do that and attract capital, they will never come to be.

Mrs. LLOYD. You mentioned in your testimony photovoltaic, solar thermal. What other technologies would you recommend for demonstration projects?

Mr. SKLAR. In my testimony the issue is—it is clearly if we have cost shares right now in photovoltaics, we need to get it more into the utility sector. Solar thermal power has been demonstrated with technology, the trough technology that came out of the '70s. We have a whole new series of stretch membrane technologies that haven't seen the light of day. We have a series of biomass technologies that are out there in terms of gasification that are profound.

The wind industry will speak about their own interests later on in this hearing, but there is a whole range of technologies from passive solar and new kinds of smart glass to what we think is some new ideas in solar water heating that are going to be very profound, and my sense is again we are a very small program. It will not take billions of dollars to do.

Mrs. LLOYD. Thank you very much. We appreciate your being with us today.

Mr. SKLAR. I appreciate the Subcommittee's indulgence for this. Thank you very much.

Mrs. LLOYD. Mr. Wolf, you may proceed.

STATEMENT OF MR. JAMES WOLF, EXECUTIVE DIRECTOR, ALLIANCE TO SAVE ENERGY

Mr. WOLF. I appreciate the opportunity to testify today on H.R. 1216 and would request that my full prepared statement be included in the record.

Mrs. LLOYD. Without objection, it is made a part of the record.

Mr. WOLF. My testimony is based on the field work the Alliance has been doing testing new technologies as well as a recent survey of industry leaders we conducted who are engaged in research and development activities with the federal government.

We commend the strategies that H.R. 1216 contains, both to expand conservation and research as well as facilitate the introduction of the technologies into the market. I would, however, make some specific recommendations that I hope the committee would consider as it marks up H.R. 1216.

The recent survey of industry leaders revealed three key findings.

First, the Department of Energy needs to expand its support of demonstration and other commercialization activities, and this has been briefly discussed, and I will return to that point.

Second, the federal government, which is the largest energy consumer in the country, can be a source of assistance in commercialization by purchasing these products that they are funding the research for for use in its own facility. The industry leaders frankly lamented the general state of federal energy management and particularly the inability or unwillingness to purchase the products that the federal government is developing with its own research dollars.

And finally that the role of the Department of Energy national laboratories and the Department itself clearly needs to be reviewed and articulated so that industry has a better understanding of what the appropriate role of each of the prospective parties is.

I would invite the committee and the staff—that on June 8th, 25 of these CEOs and directors of research are coming into Washington for a meeting, and you are welcome to attend that meeting. We will extend a formal invitation shortly.

Congressman Sharp will be meeting with them at 9:30 that morning, and the entire committee and staff are welcome to attend.

On the point of why the Department needs to expand its support of demonstration activities, we asked 11 specific questions of these industry leaders, one of which was touched upon.

We asked why are so many of the technologies that are invented here seemingly only produced overseas?

And one of the responses we got back was the willingness of other governments to participate in other aspects of the commercialization process, or what the Assistant Secretary, Mr. Berg, called the continuum of technology development, and I think he is quite right in that characterization.

For the previous eight years, the Administration has had an absolute hard and fast rule that only long-term generic research was being funded. This led to the development of factors of some prom-

ising technologies which are languishing and not being commercially produced.

I implore Dr. Berg, when he said they are reevaluating, what aspects of the technology to continuum that the Department will fund.

Now, providing strong and stable funding for demonstration and commercialization is a significant departure from current practice. However, in demonstration the industry leaders indicated a willingness and the desire in fact to have this cost shared. They thought that would be quite appropriate. But I think the important point is that they do need flexibility.

Madam Chairman was asking before of Mr. Sklar what the appropriate number would be. I don't know if there is an appropriate number. For example, some of the smaller firms in the industry—and there are many in the conservation industry which are quite small—said cost sharing is just a significant problem to them when they go to the capital markets. They were quite willing, for example, that the government could take an equity position and say if this product is successful let the government recoup its investment in that way, and so they are indicating the desire and the willingness to cost share, but indicated the need for flexibility.

I would also point out that the demonstration activities that they recommended should not all be done solely in response to a request for proposal the way it is typically done by the Department. This, frankly, discourages innovation.

I recommend that at least a portion of the funds be reserved for unsolicited proposals so that smaller, creative firms can put any proposal into the Department that the Department will have the flexibility to fund for some aspects of demonstration projects.

The second point noted from the survey is the federal government as purchaser, and as I say, the focus of these industry leaders was not to reduce the taxpayer's expense for the federal energy bill. It was really that the federal energy management could be one of the best ways to assist commercialization of new technologies—new windows, new lighting. None of it is currently getting into the federal marketplace, and frankly it is not just the Department of Energy responsibility in this case.

I encourage the committee to look at both the General Services Administration as well as the Department of Energy FEMP program, have them involved when the basic funding decisions and R&D are made about whether or not this technology will be purchased by the government for use in its facilities.

I note the Defense Department, which is the largest funder of basic research, purchases the technology that they develop, and similarly we should look for the federal government here to be a purchaser of the technology.

On specific recommendations on H.R. 1216 that I would make, the multi-year authorization concept is very helpful, and the industry leaders spoke about the fact that several times they were left dangling, whether or not the project was going to be continued for the next year.

However, I also want to point out that I shouldn't overstate the benefits of the multi-year authorization because the industry leaders were also very cognizant of the fact that frequently the prob-

lem was not an authorization but the commitment of the Congress to an appropriation or to the Administration to the basic continuation of the program itself.

So one thing I would encourage the Congress to look at and examine is in the context of a two-year, both budget and appropriation cycle, and I would look to the Administration to make a long-term commitment and statement of support for these programs.

On the authorization levels, Mr. Fawell has pointed out that indeed it is in fact very modest. I would say it is in fact too modest. Several of the programs in the conservation and efficiency area in real terms are slated for a decrease in 1991.

I find that very strange when we are looking at both the Administration and others looking to energy efficiency to play a large part of our future energy picture due to environmental concerns like global warming as well as other issues.

The Department of Energy's own planning process in multi-year plans show that many good research projects in energy efficiency are unfunded or underfunded at the present time. I recommend the committee consider the authorization levels proposed in H.R. 1078, which is the Global Warming Prevention Act of 1989, which was introduced by Congresswoman Schneider and over 150 other co-sponsors.

Now, I certainly recognize the difficulty of the budget deficit. We are well aware of that problem, and what I propose the committee should do to address that is look at the overall allocation of research priorities within the Department. I think that is what really needs to be addressed in the context of the budgetary problem.

Even if this bill were adopted, I think it is important to recognize that conservation would be only 5 percent of the Department of Energy's R&D budget in 1991, assuming that the other portions remain unchanged. That is just bad priorities from a national perspective.

What I suggest that the committee do is either in legislation or encouragement of the Department give the Department priorities to and criteria for the entire R&D budget because right now we are in essence competing for nuclear funding, fossil fuel funding, environment funding, basic science renewable, but overall, perhaps in part because of the Congressional committee structure, nobody is stepping back and saying where is all this money on an R&D basis going to.

I think that needs to be done, and I think that if that were done the conservation would certainly get more than 5 percent of the Department's research and development budget.

The concept of joint ventures which the committee puts forth in this bill is to be commended in concept, in Section 6. As I mentioned, however, I don't think the 30 percent commitment of non-federal funds should be an absolute requirement and unsolicited proposals should also go forth.

However, while joint ventures are proposed for many of the renewable technologies, I note that there is none established in the bill to promote the use of conservation or efficiency technologies. So I suggest that these be incorporated either as a joint venture or, more broadly, as a demonstration program.

Now, I don't think that a specific technology need be named for the efficiency or components, but it could include, for example, technologies as diverse as new windows, new lights, motors, insulation, furnaces, or even engine components.

The point I made addressing the federal purchasing and the failure of the federal government to really look at its R&D as a source to reduce the federal energy bill I think could be addressed in Section 8 of the bill, which does call upon the federal energy management program to disseminate information. But I think that should be broadened in Section 8 to encompass more than just dissemination of information and have an aggressive program involving both the General Services Administration and the federal energy management program active in the research phase and the commitment that when these products are suitable they will be purchased for use in federal facilities.

I thank the Committee for the opportunity to testify, and as I said, we wholeheartedly endorse the general approach of H.R. 1216 and hope these suggestions can be incorporated in the bill.

[The prepared statement of Mr. Wolf follows:]

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James L. Wolf
Executive Director

Testimony of James L. Wolf
Executive Director
Alliance to Save Energy
before the
Subcommittee on Energy Research and Development
Committee on Science, Space and Technology
United States House of Representatives
May 16, 1989

I appreciate the invitation to testify before the Committee regarding energy efficiency as it relates to H.R. 1216, the Renewable Energy and Energy Efficiency Technology Competitiveness Act of 1989. The Alliance to Save Energy is a national nonprofit coalition of government, business and consumer leaders dedicated to increasing energy efficiency. We conduct research, pilot projects, educational programs and policy advocacy to achieve this goal.

My testimony today is based upon the extensive field work we do in testing new technologies and working with manufacturers, utilities, the national laboratories and other organizations to design programs to facilitate the introduction into the market of energy efficient products. It also is based upon a recent survey we conducted of firms engaged in federal conservation research and development activities. I am submitting with this testimony a copy of the results of that survey entitled The Department of Energy's Conservation R&D Programs: Results of a Survey of Industry Leaders.

We commend the strategies that H.R. 1216 contains on energy efficiency to expand conservation research and development activities and to facilitate the introduction of the technologies into the market. I will make some specific recommendations that I hope will be incorporated in the legislation to further its goals.

Many of the technologies that are now standard -- such as flame retention oil burners that save over 20% from earlier models -- were invented by private industry in successful collaboration with the national laboratories. There are numerous examples of federal investments in research and development that have resulted in energy efficient products -- benefiting both our national security, international competitiveness and the environment.

The country can make significant strides today to improve its energy efficiency using existing cost-effective technology. Programs to accelerate the market penetration of these technologies are needed; this is a related but distinct question from the focus on commercialization of technologies from the research phase that the bill does address. Many of the proposed programs to assist commercialization from research will also foster the faster adoption of the technologies in the marketplace. I believe, however, that separate programs should also be designed to achieve this objective.

The continued research and development of new technologies is one reason why the "conservation potential" for our economy can continue to expand. Our challenge is to continue to expand the slate of cost-effective technologies as the economy grows and existing technologies achieve their market potential.

SURVEY OF INDUSTRY

The Alliance recently surveyed senior executives of organizations engaged in federal conservation R&D. Over 30 executives responded to the questions, and a copy of the report analyzing their responses is attached to my testimony. The responses are very informative from a qualitative perspective but do not represent a statistical sampling.

Three key findings emerged from the survey that have direct relevance to H.R. 1216 and suggest some specific modifications to the bill. First, DOE should expand its support of demonstration and other commercialization activities. Second, the federal government should foster the market for energy efficiency technologies through a purchasing program. Finally, while there is strong support for a significant federal role in R&D, the roles of DOE and the national laboratories in conservation R&D should be reviewed, clearly articulated, and communicated to industry.

DOE should expand its support of demonstration projects and other commercialization activities.

Since 1981, DOE's conservation R&D efforts have concentrated on long-term basic research on generic technologies; funding for specific products and demonstration-oriented activities has diminished. New energy efficiency technologies that have been funded through the proof-of-concept stage often never make it to the market because of the high costs and risks of commercialization. In some cases, these concepts are picked up and commercialized by overseas competitors. As a result, the U.S. lags in getting new energy-efficiency technologies into production.

As one executive noted in response to the survey: "In the development of a new technology or product there is a continuum

of activity: basic research, applied research, laboratory model, proof-of-concept unit, field test units, pilot production and full scale production. . . . The technical risk is reduced as one goes from step to step but the economic investment increases in each progressive step. . . . There is often a funding gap between the feasibility development and product development." It is especially difficult for smaller firms to raise the capital to complete the cycle of full scale commercialization.

These problems can be addressed by providing strong and stable funding for demonstration and commercialization activities. This would be a significant departure from current practice. While industry should be expected to contribute financially to these projects, the cost-sharing requirements should be eased for smaller firms -- perhaps through a mechanism that would recapture the government's investment after a product is successfully commercialized.

I recommend that all research not be sponsored and awarded in response to a request for proposals. Because of the complexity and expenses involved in responding to requests for proposals, many firms -- particularly smaller ones -- noted that reserving a portion of the funds for unsolicited proposals would be very beneficial. It would both encourage innovative proposals and facilitate these firms participating in federal R&D.

The perceived need for federal participation in demonstration and commercialization activities is resounding from the survey.

The federal government should help foster the market for energy efficiency technologies through a purchasing program.

Many firms noted that the government is a massive consumer of energy-related technology, but does not use its purchasing power to assist in the market development of efficiency innovations that have been nurtured through federal R&D funding. The comments received are more significant than just the general lament about the state of federal energy management.

In this context, it is helpful to make an analogy to the Defense Advanced Research Projects Agency (DARPA) within the Department of Defense. This program is working with industry to support development of technologies critical to future identified defense needs. The firms have a market for their product when it is developed. As has been observed by many, the technologies will have significant benefits in the civilian sector as well. DARPA is able to accelerate introduction of products to the civilian sector both because of the R&D funding support and the knowledge that a receptive market for initial product sales exists.

Despite the vast need for improvements in federal energy efficiency, and the money allocated for research, there is no consideration given during the R&D funding decisions to the

purchase of the technology developed. This clearly should be remedied by DOE working with GSA.

Even DARPA may have a role in energy efficiency. If DARPA's focus is technologies critical to our national defense, does not energy efficiency fit within that category? We well know the threat to our security posed by excessive reliance on imported oil. Reducing that dependence could be an important component of DARPA activities -- the Department of Defense is, after all, the largest energy consumer in the country.

The roles of DOE and the national laboratories in conservation R&D should be reviewed, clearly articulated and communicated to industry.

There was strong support for a significant -- even expanded -- federal role in R&D. However, many firms indicated that they do not have a clear understanding of DOE's program goals or current R&D activities. The process by which broad goals are translated into program and funding priorities is unclear. Differences between societal goals -- such as national security and environmental quality -- and the private sector's goals must be recognized in program design. DOE should work more closely with industry and the national laboratories to determine the scope and direction of R&D, and to ensure the results of the laboratories' work are transferred to industry.

The management direction of DOE's programs must ultimately reside with DOE officials and not private industry. It is clear, however, that industry needs to be more involved in advisory councils and other types of programs. Only then will our national laboratories, the Department and industry be able to cooperatively work together and maximize the benefits we can achieve from federal R&D. H.R 1216 establishes many industry advisory councils and is to be commended for adopting this approach.

SPECIFIC RECOMMENDATIONS ON H.R. 1216

Based on the Alliance's industry survey and our other activities in the efficiency area, I have several specific recommendations on H.R. 1216.

o Multi-year authorizations: The concept of multi-year authorizations is beneficial, although the real problem from the industry perspective has been the lack of program continuity due to both the previous Administration's attempts to drastically curtail it and the uncertainty of appropriations. I encourage the Congress to adopt a 2 year budget and appropriations cycle. Research and development, by its nature, is not well suited to a one year planning horizon.

o Authorization levels: The authorization levels in the bill for conservation are too modest given the potential of energy

efficiency to ameliorate many national problems -- particularly global warming. The overall increase is approximately 15.6% over 2 years for conservation programs -- only a slight real increase assuming a modest inflation rate. Some specific programs are in fact decreased in real terms in 1991 from 1989 levels.

In H.R. 1216, the overall level for conservation would still be over 48% lower than 1980 -- at a time when there now is general consensus that our focus on efficiency should be dramatically increasing due to global warming dangers, increasing oil imports, and concerns about international competitiveness. The Department of Energy's own planning processes and multi-year plans show that many research projects in energy efficiency are unfunded or underfunded at present.

The proposed decrease in policy management and direction, while a small item, is one that I want to highlight. The legislation proposes to decrease this from $3 to 2 million. I recommend, however, that this be increased. The results from the industry survey clearly called for more direction and coordination of the research programs, and a careful examination of how they relate to other critical issues -- such as the environment. These dollars can markedly improve the "bang for the buck" we receive with the dollars doing the actual research.

I recommend the Committee adopt the authorization levels proposed in H.R. 1078, the Global Warming Prevention Act of 1989, which already has over 100 co-sponsors.

While I recognize the difficulty of a significant increase in the programs due to the budget deficit, I propose a reallocation of research funding priorities within the Department of Energy. If the rest of the Department's budget were to remain unchanged from its 1989 levels, the increase in conservation proposed in this bill to $177 million for 1991 would put it just over 5% of the total R&D program in the Department. This is simply inadequate to the task at hand. I recommend the Committee enact legislation to provide criteria and guidance for the overall research priorities at the Department considering factors such as global warming, national security, and the likelihood of near term success.

o <u>New Initiatives</u>: The legislation is to be commended for encouraging the Secretary in Section 5 to submit new initiatives. Numerous initiatives are forwarded each year to the Congress and the Administration by the Alliance in conjunction with the American Council for an Energy Efficient Economy, The Energy Conservation Coalition, and other groups. Some for this year, for example, include research on alternatives to CFCs for refrigeration and insulation, microwave ceramic sintering, and weatherization program improvements. The Secretary should also be asked to submit the top 5 programs which just missed his cut-off for new initiatives, with an explanation for why they were ranked at lower priority than those he recommended. This will

give the Congress more information about the research potential and encourage the development of new ideas.

o Joint Ventures: Section 6 is to commended in concept. To improve its effectiveness, I recommend that the 30% commitment of non-federal funds not be an absolute requirement. Provision should be made to allow some exceptions to the rule. As revealed in the industry survey, an absolute 30% requirement may be a significant barrier to some firms. Similarly, some proposals should be allowed to go forward without a competitive request for proposals -- unsolicited proposals should be encouraged.

While joint venture arrangements are established for many of the renewable technologies, there is none established to promote commercialization of energy efficient technologies domestically. I suggest one specifically be established for this purpose. The technologies need not be named, but could include technologies as diverse as windows, lights, motors, insulation, furnaces, or engine components. (Section 6(C)(6) comes the closest to incorporating energy efficient technologies, but it is focused on export of technology.) I recommend the authorization be at least $15 million for this purpose.

o Federal Purchasing to Facilitate Commercialization:

I recommend the legislation incorporate specific provisions providing for some form of ready access to the federal market for products developed with federal R&D funds, as well as for other products to demonstrate energy efficiency or renewable energy technologies. This could be accomplished through expanding Section 8 to encompass more than just the dissemination of information.

The Federal Energy Management Program, and GSA, should be active partners in the acquisition of research products developed with federal dollars. They could be required to make a purchasing commitment when the research funding is approved. Indeed, the federal commitment to purchase products was identified by industry as one of the best ways to assist commercialization. It is simply not being done now.

CONCLUSION

By enhancing research to develop new conservation technologies and structuring programs to assist their introduction into commercialization, H.R. 1216 will provide numerous benefits to the country. The benefits include a major step in mitigating the threat of global warming, enhanced national security, more affordable housing, and a more competitive economy.

Mr. STALLINGS. (presiding) Thank you, Mr. Wolf.
Dr. Otte.

STATEMENT OF DR. CAREL OTTE, GEOTHERMAL RESOURCES ASSOCIATION

Dr. OTTE. Mr. Chairman, members of the committee, my name is Carel Otte, and I am recently retired as President of UNOCAL's Geothermal Division and I am now a consultant to the company.

I am appearing today on behalf of the Geothermal Resources Association.

The GRA endorses the objectives of H.R. 1216, the Renewable Energy and Energy Efficiency Technology Competitiveness Act of 1989 and makes the following recommendations where the bill might address the needs of the geothermal industry.

One, increase the funding levels.

Two, target a large portion of the funding to advanced hydrothermal, water dominated geothermal resources, particularly the research, thereby assisting the industry in developing technologies that will in turn reduce development costs.

And, three, establish an advisory committee on geothermal energy technology and include a representative from the geothermal sector on the Secretary's Advisory Committee on Renewable Energy Technology.

Geothermal energy is a domestic alternative resource that is being used to generate electricity and in direct heat application in competition with more traditional fossil fuel sources. It contributes to our energy security, and it saves fossil fuels for higher priority uses.

Scientists at the U.S. Geological Survey estimate that the electrical energy recoverable from high temperature geothermal systems in the United States over a 30-year period is about 23 million kilowatts of generating capacity. While this may just be a fraction of the national electricity requirements, consider that 23 million kilowatts represents the energy equivalent of about 800,000 barrels of imported crude oil per day.

By the end of calendar year 1988, approximately 3000 megawatts of geothermal power capacity had been constructed in the United States. By the mid-1990s, the geothermal industry may be responsible for generating more than 4000 megawatts of electricity from an abundant and environmentally benign fuel source.

Studies of California, for example, suggest that the geothermal energy resources could power nearly 12 percent of that state's electricity needs. Despite the tremendous geothermal resource potential, the pace of exploration for geothermal energy slowed considerably with the price decline of petroleum in 1986. If it were not for completion of some existing projects with favorable PURPA sales contracts, development would have stagnated even more.

During the 1980s, budget cuts have led to significant declines in DOE's geothermal technology program; for instance, from a total budget of 158 million in fiscal year 1979 to 19.5 million in fiscal year 1989. These drastic reductions were imposed just at a time when the results of a technology development program could have

been utilized to make the geothermal industry more competitive with conventional fuels.

A major provision of H.R. 1216 is authorization for joint research and development ventures. The geothermal industry is already participating in several joint industry/Department of Energy projects. This industry/government effort was initiated in response to the drastic cuts in DOE research and development funding. With continued government funding cutbacks and declining oil prices, even these extremely worthwhile joint initiatives are suffering.

The reduction of domestic petroleum production since the price declines and the increasing dependence on imported crude oil puts the United States in a very vulnerable strategic and economic condition. This vulnerability will worsen with continued dependence on imported energy. This dependence grows as prices remain low and supplies are abundant. The use of imported energy, which supplied over 21 percent of U.S. energy use in 1988, is expected to grow at a very rapid annual rate of about 4 percent between 1988 and the end of this century.

DOE projects that imported energy will provide almost 30 percent of the total energy use in the United States in the year 2000, and at this rate of use by 1995 the United States might be spending $80 billion a year on crude oil importation.

The National Research Council of the National Academy of Sciences completed a study in '87 and concluded that there exists a very large geothermal resource base, but that additional research and technology development is needed to make this domestic energy resource fully exploitable.

Specifically, the study recommended that the DOE geothermal technology program be funded at a stable level over a five-year period at higher amounts than currently provided. Only in this way can we maintain a viable R&D program for both near-term and long-term geothermal resource development.

The budget level recommended by the Council for all geothermal categories was an average of $33 million annually over the five years.

As research goals are met, this annual budget could decline. In light of inflation and passage of time, these numbers should probably be increased by about 20 percent.

Mr. Chairman, this National Research Council study still stands as the single most definitive report on the DOE geothermal technology program, and with your permission, I would like to submit the study for the record of this hearing.

Mr. STALLINGS. Without objection, it will be included. [See Appendix II]

Dr. OTTE. Since issuance of this National Research Council report, no steps have been taken to implement its recommendations, and the national energy supply imbalances become increasingly more critical.

Geothermal energy can play an important role in reducing our dependence of imported fossil fuels, thereby improving our balance of trade, our energy dependence, and also contribute to addressing the global warming effects of burning fossil fuels.

Thank you very much for the opportunity to present these views, and the GRA endorses the goals of this legislation.

[The prepared statement of Dr. Otte follows:]

STATEMENT OF DR. CAREL OTTE
UNOCAL CORPORATION
BEFORE THE
SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT
OF THE
COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES
WASHINGTON, D.C.
MAY 23, 1989

MY NAME IS CAREL OTTE. I AM RECENTLY RETIRED AS PRESIDENT OF UNOCAL'S GEOTHERMAL DIVISION AND AM NOW A CONSULTANT TO THE COMPANY. I AM APPEARING TODAY ON BEHALF OF THE GEOTHERMAL RESOURCES ASSOCIATION (GRA).

THE GRA ENDORSES THE OBJECTIVES OF H.R. 1216, THE "RENEWABLE ENERGY AND ENERGY EFFICIENCY TECHNOLOGY COMPETITIVENESS ACT OF 1989" AND MAKES THE FOLLOWING RECOMMENDATIONS WHERE THE BILL MIGHT BETTER ADDRESS THE NEEDS OF THE GEOTHERMAL INDUSTRY: (1) INCREASE THE FUNDING LEVELS; (2) TARGET A LARGE PORTION OF THE FUNDING TO ADVANCED HYDROTHERMAL (WATER-DOMINATED GEOTHERMAL RESOURCES) RESEARCH THEREBY ASSISTING THE INDUSTRY IN DEVELOPING TECHNOLOGIES THAT WILL, IN TURN, REDUCE DEVELOPMENT COSTS; AND (3) ESTABLISH AN ADVISORY COMMITTEE ON GEOTHERMAL ENERGY TECHNOLOGY AND INCLUDE A REPRESENTATIVE FROM THE GEOTHERMAL INDUSTRY ON THE SECRETARY'S ADVISORY COMMITTEE ON RENEWABLE ENERGY TECHNOLOGY.

GEOTHERMAL ENERGY IS A DOMESTIC ALTERNATIVE RESOURCE THAT IS BEING USED TO GENERATE ELECTRICITY AND IN DIRECT HEAT APPLICATION IN COMPETITION WITH MORE TRADITIONAL FOSSIL FUEL SOURCES. IT CONTRIBUTES TO OUR ENERGY SECURITY AND SAVES FOSSIL FUELS FOR HIGHER PRIORITY USES. SCIENTISTS AT THE U.S. GEOLOGICAL SURVEY ESTIMATE THAT THE ELECTRICAL ENERGY RECOVERABLE FROM HIGH TEMPERATURE GEOTHERMAL SYSTEMS IN THE

UNITED STATES OVER A 30-YEAR PERIOD IS ABOUT 23 MILLION KILOWATTS OF POWER. WHILE THIS MAY BE JUST A FRACTION OF THE NATIONAL ELECTRICITY REQUIREMENTS, CONSIDER THAT 23 MILLION KILOWATTS REPRESENTS THE ENERGY EQUIVALENT OF ABOUT 800,000 BARRELS OF IMPORTED CRUDE OIL PER DAY. BY THE END OF CALENDAR YEAR 1988, APPROXIMATELY 3,000 MEGAWATTS OF GEOTHERMAL POWERED CAPACITY HAD BEEN CONSTRUCTED IN THE UNITED STATES. BY THE MID-1990'S THE GEOTHERMAL INDUSTRY MAY BE RESPONSIBLE FOR GENERATING MORE THAN 4,000 MEGAWATTS OF ELECTRICITY FROM AN ABUNDANT AND ENVIRONMENTALLY BENIGN FUEL SOURCE. STUDIES OF CALIFORNIA, FOR EXAMPLE, SUGGEST THAT GEOTHERMAL ENERGY RESOURCES COULD POWER NEARLY 12 PERCENT OF THAT STATE'S ELECTRICAL NEEDS.

DESPITE THE TREMENDOUS GEOTHERMAL RESOURCE POTENTIAL, THE PACE OF EXPLORATION FOR GEOTHERMAL ENERGY SLOWED CONSIDERABLY WITH THE PRICE DECLINE OF PETROLEUM IN 1986. IF IT WERE NOT FOR THE COMPLETION OF SOME EXISTING PROJECTS WITH FAVORABLE PURPA SALE CONTRACTS, DEVELOPMENT WOULD HAVE STAGNATED EVEN MORE.

DURING THE 1980'S BUDGET CUTS HAVE LED TO SIGNIFICANT DECLINES IN THE DOE'S GEOTHERMAL TECHNOLOGY PROGRAM (E.G. FROM A TOTAL BUDGET OF $158 MILLION IN FISCAL YEAR 1979 TO $19.5 MILLION IN FISCAL YEAR 1989). THESE DRASTIC REDUCTIONS WERE IMPOSED JUST AT A TIME WHEN THE RESULTS OF A TECHNOLOGY DEVELOPMENT PROGRAM COULD HAVE BEEN UTILIZED TO MAKE THE GEOTHERMAL INDUSTRY MORE COMPETITIVE WITH CONVENTIONAL FUELS.

A MAJOR PROVISION OF H.R. 1216 IS AUTHORIZATION FOR JOINT RESEARCH AND DEVELOPMENT VENTURES. THE GEOTHERMAL INDUSTRY IS ALREADY

PARTICIPATING IN SEVERAL JOINT INDUSTRY/DEPARTMENT OF ENERGY PROJECTS. THIS INDUSTRY/GOVERNMENT EFFORT WAS INITIATED IN RESPONSE TO THE DRASTIC CUTS IN DOE RESEARCH AND DEVELOPMENT FUNDING. WITH CONTINUED GOVERNMENT FUNDING CUT-BACKS AND DECLINING OIL PRICES, EVEN THESE EXTREMELY WORTHWHILE JOINT INITIATIVES ARE SUFFERING.

THE REDUCTION OF DOMESTIC PETROLEUM PRODUCTION SINCE THE PRICE DECLINES AND THE INCREASING DEPENDENCE ON IMPORTED CRUDE OIL PUTS THE UNITED STATES IN A VERY VULNERABLE STRATEGIC AND ECONOMIC CONDITION. THIS VULNERABILITY WILL WORSEN WITH CONTINUED DEPENDENCE ON IMPORTED ENERGY. THIS DEPENDENCE GROWS AS PRICES REMAIN LOW AND SUPPLIES ARE ABUNDANT. THE USE OF IMPORTED ENERGY, WHICH SUPPLIED 21.3 PERCENT OF U.S. ENERGY USE IN 1988, IS EXPECTED TO GROW AT A VERY RAPID ANNUAL RATE OF 4.0 PERCENT BETWEEN 1988 AND THE END OF THIS CENTURY. DOE PROJECTS THAT IMPORTED ENERGY WILL PROVIDE ALMOST 30 PERCENT OF THE TOTAL ENERGY USED IN THE UNITED STATES IN 2000 AND AT THIS RATE OF USE, BY 1995 THE UNITED STATES MIGHT BE SPENDING $80 BILLION A YEAR ON OIL.

THE NATIONAL RESEARCH COUNCIL OF THE NATIONAL ACADEMY OF SCIENCES COMPLETED A STUDY IN 1987 AND CONCLUDED THAT THERE EXISTS A VERY LARGE GEOTHERMAL RESOURCE BASE, BUT THAT ADDITIONAL RESEARCH AND TECHNOLOGY DEVELOPMENT IS NEEDED TO MAKE THIS DOMESTIC ENERGY RESOURCE FULLY EXPLOITABLE. SPECIFICALLY THE STUDY RECOMMENDED THAT THE DOE GEOTHERMAL TECHNOLOGY PROGRAM BE FUNDED AT A STABLE LEVEL OVER A FIVE-YEAR PERIOD AT HIGHER AMOUNTS THAN CURRENTLY PROVIDED. ONLY IN THIS WAY CAN WE MAINTAIN A VIABLE R&D PROGRAM FOR BOTH NEAR-TERM AND LONG-TERM GEOTHERMAL RESOURCE DEVELOPMENT. THE

BUDGET LEVEL RECOMMENDED BY THE COUNCIL FOR ALL GEOTHERMAL CATEGORIES WAS AN AVERAGE OF $33 MILLION ANNUALLY OVER THE FIVE YEARS. AS RESEARCH GOALS ARE MET THIS ANNUAL BUDGET COULD DECLINE. IN LIGHT OF INFLATION AND PASSAGE OF TIME THESE NUMBERS SHOULD PROBABLY BE INCREASED BY ABOUT 20 PERCENT. MR. CHAIRMAN, THIS NATIONAL RESEARCH COUNCIL STUDY STILL STANDS AS THE SINGLE MOST DEFINITIVE REPORT ON THE DOE GEOTHERMAL TECHNOLOGY PROGRAM. WITH YOUR PERMISSION, I WOULD LIKE TO SUBMIT THE STUDY FOR THE RECORD OF THIS HEARING.

SINCE ISSUANCE OF THIS NATIONAL RESEARCH COUNCIL REPORT, NO STEPS HAVE BEEN TAKEN TO IMPLEMENT ITS RECOMMENDATIONS AND THE NATIONAL ENERGY SUPPLY IMBALANCE HAS BECOME INCREASINGLY MORE CRITICAL. GEOTHERMAL ENERGY CAN PLAY AN IMPORTANT ROLE IN REDUCING OUR DEPENDENCE OF IMPORTED FOSSIL FUELS, THEREBY IMPROVING OUR BALANCE OF TRADE, OUR ENERGY DEPENDENCE AND ALSO CONTRIBUTE TO ADDRESSING THE GLOBAL WARMING EFFECTS OF BURNING FOSSIL FUELS.

THANK YOU VERY MUCH FOR THE OPPORTUNITY TO PRESENT THESE VIEWS ON H.R. 1216. ONCE AGAIN, THE GRA ENDORSES THE GOALS OF THIS LEGISLATION.

Mr. STALLINGS. Thank you, Dr. Otte.

Mr. Wolf, you mentioned the need to improve technology transfer from the national laboratories.

Could you give us your assessment of the current technology transfer program of the Department and give us your recommendations of ways we might improve that?

Mr. WOLF. The Department we believe over the past year and a half has made a good effort to improve its technology transfer programs because I think they recognize that in fact they were a failure. We encourage them to involve industry advisory councils more, both in the development of the basic research, which we think then will facilitate the technology transfer component.

We also think it is particularly difficult if you look at what in English we call the role of the national laboratory and you need a bridge from a pure researcher, if that is what the national laboratories are to be, to someone who understands the needs of whoever is responsible to commercialize the product, whether it is the producer of the product, ultimately the user in the sense of a homebuilder or a car manufacturer, and those are the people as yet that we see have not been brought into the process of understanding what the technologies' potential are and understanding what their needs are as the technology is developed.

Mr. STALLINGS. You state some companies should be excused from cost share demonstrations.

Can you give us an example of the criteria that a company should meet and not be required to provide funds?

Mr. WOLF. By excuse, I think there are the alternate mechanisms for direct cost sharing. The one small company, for example, that said he was quite willing to give up an equity position in the company, saying but I cannot raise the capital;if the up-front capital expenditure is required from my company, I would not be able to do that. But they were willing to say I am willing to sit down with the government if they have the flexibility so that there will be other mechanisms for the government to recoup its investment.

Mr. STALLINGS. Let me pose a couple of questions to you.

You state that the pace of exploration for geothermal energy slowed when oil prices declined.

Are we going to be always tied to that? What can we do to encourage more geothermal exploration in this age of lower prices?

Dr. OTTE. Well, two things happened, Mr. Chairman. They are somewhat interrelated, but they are still separate.

One is the prices declined because there was this very successful massive conservation effort taking place when the price ran up in the late '70s, in '78, '79, with the Iranian crisis and the oil price run-up. There was this massive price run-up, and with it came price-induced conservation, and this of course resulted in a cutback of electricity use generation, which is predominantly the outlet for geothermal.

So the utility companies didn't have a need for much additional capacity. Many of the large generation facilities were completed at the time, and they have come online in the early '80s in the meantime. So there was particularly in the Western United States somewhat of a glut of power generation, and if they just don't need the

power naturally a person is not going to drill the holes in the ground.

But, secondly, what happened with it at the same time was that with the price decline that followed sort of in the mid-'80s, the dramatic price decline in '86, where oil went from roughly $30 a barrel to $10 a barrel, the oil was readily available, and with those price fluctuations and those low prices geothermal resources are just not competitive. So there was basically then a market development that ceased to exist and we were not competitive.

The latter factor, with time, will be self-correcting. If that scenario that I referred to in my testimony, where I think with the increased importation of crude oil, which I think is inevitable the way our domestic production is going, that—and with the increased importation of fossil fuels from abroad, I think the prices will begin to run up again.

There is no doubt about that, and so that aspect will also be self-correcting, and at the same time the excess generating capacity that the utilities have, particularly in the Western United States, is also being eaten into. The systems are growing, so that reserve capacity is beginning to decline.

So to a certain extent some of it will be self- correcting. However, what is happening to the small developers in the industry, they—a lot of them have gone out of business in the meantime.

Much in the petroleum industry traditionally has been the so-called independent—well, the independent sector and the geothermal industry. That independent sector, the private entrepreneur, the wildcatter, that sector has declined considerably, and that is very frightening.

I am a major company man myself, but at the same time that initiative and the entrepreneurial spirit that comes from the private entrepreneur and the investor is very desirable, and that has dried up.

So I think specifically what can be done—there have been parallel discussions with other committees on the Hill here, both in the House as well as in the Senate side, in the extension of energy tax credits, as has—it was a struggle. It was extended again last year at the eleventh hour.

So for 1989 the energy tax credits were extended. They have played an important role, and I think it has provided an incentive.

I particularly like the tax credits or depletion allowances because they are success oriented. They are not direct grants by the government, but they say, okay, Joe, why don't you go out and spend your money if you have a hot prospect and if you succeed we will give you a benefit.

It is success oriented, and in that type of stimulation that brings the private sector into it, and I think—in that regard I feel more could be done. Much of that has been taken away, of course, in the Tax Revision Act of '86, as you well know, by creating the so-called level playing field. But I feel in the past the so-called incentives are for research development or high risk development have been successful, and they have been successful in the petroleum side, too.

Mr. STALLINGS. Thank you, Doctor.

Mr. Morrison.

Mr. MORRISON. Just one question, Mr. Chairman, and, Dr. Otte, for you.

You mentioned the geothermal industry has already participated in several joint industry/DOE projects.

Could you describe what a couple of those projects might be?

Dr. OTTE. Well, they aren't—first of all, it was very interesting to hear Assistant Secretary Berg testify because it was one of his predecessors that I talked to early in the Reagan Administration, when he basically was an instrument in dismantling the existing DOE research project program and going to the long-term effort, and I challenged him at that time.

It was Assistant Secretary Trible. I know him still well, and I said, hey, we need that, what is being done? He said, well, you people can do that yourselves. And I said, no, we cannot do that.

And it was at that time that I challenged him. I said, look, we would like to see these programs continued and, if you are willing to continue to provide some funding, then let me see whether I can get some co-funding from the private sector to come with you.

The DOE had a very important role to play. If the Union Oil Company goes out or the Chevron or the Exxons of the world go out and say, hey, and go to the industry and say, why don't you give me some of your money and we will do research, no money will appear, obviously for very good reasons. It is a very competitive business, and they are not going to give me their money.

But if it is a national laboratory or a university facility that becomes sort of the custodian, then industry will—it becomes the catalyst by which money can be generated, and this indeed is what happened.

So some specific projects were singled out where maybe the basic research had been conducted but the development was lacking. It was not ready for the marketplace.

Now, the high risk part in geothermal technology is not in the conversion side. Once we have the resource on top of the ground we can generate electricity. So therefore the demonstration aspects that are so pivotal in your legislation is not so important for us. We have already demonstrated that we can generate electricity. We are online. We are producing. We are competitive with the alternative fuel sources.

But it is the resource side that we poorly understand, and it is the resource side—the bulk of the expenditures of the development for the resource are drilling, and this is a tough drilling business. Drilling for the oil industry that we have to borrow from was basically in a soft rock environment where oil and gas is being found. We are drilling in the type of terrain that is mining country, where you diamond drill or you sink shafts, but you don't drill with a drilling rig like you do in Texas in drilling for oil and gas, and yet we are using rotary tools to develop it, and it is a high temperature environment and it is very hostile.

So it is a perfection of the drilling tools. Traditionally, geothermal drilling is four and more than four times as expensive as an oil-gas well to an equivalent depth. We need to bring those drilling costs down. We need better drill bits, better elastomers, higher temperature logging tools, alloys that are corrosion resistant, and

those are some of the things that we are working on under the joint development program.

We have a high temperature downhole televiewer, kind of like a video camera, that goes down and it searches, so that we can look what the rocks look like. High temperature. We are working at 5-, 6-, 700 degrees Fahrenheit, and you can envision putting a television set in an environment like that. In the past everything would burn up and come out like a stump, like burn up like charcoal.

But we are doing it now. These are the type of things, and it is jointly funded. It is being directed by Sandia. We are giving our money in it, and the government puts the money in Sandia, and it is working well. Very selective projects. We have a steering committee, joint government/private sector. It is modest, but it is going. We would like to do more.

Mr. MORRISON. Do you sense that the Department is going to be responsive if we don't provide specific directions in geothermal research areas?

Dr. OTTE. Oh, I would join one of the earlier gentlemen. I don't know whether Mr. Wolf here or Mr. Sklar made the statement that basically DOE—I think DOE itself on their own initiative would like to conduct these programs, but OMB has been the stumbling block.

But also an earlier remark I heard that maybe Mr. Wolf made—and I concur in that—maybe the whole DOE research budget, not the defense aspect but the research aspect of DOE, needs to be examined in the overall priorities.

Much money goes into fusion, you know. I don't worry about the year 2020. If I can't survive next year and the year after, I don't care about the year 2020. In my industry that is what we are fighting.

Mr. MORRISON. This legislation is an effort, if you will, to do some reordering in an area where it is difficult to reorder because we all come equipped with our own special interests.

Well, thank you for your response.

I sense an enthusiasm to work with you and the industry that you represent and make some things happen in this area.

Thank you, Mr. Chairman.

Mr. STALLINGS. Thank you.

Mr. Fawell.

Mr. FAWELL. Just a comment again. I wondered how you gentlemen might react to it. Time and again I have heard people say or refer to cost efficiency as being very vital in reference to the sale of energy, and what everybody looks at is the cost efficiency and price competitiveness in reference to fossil fuels, which seemingly always win the game.

I am a great believer in the free enterprise system, in supply and demand and market price being what we look at, but yet I wonder if we—and again in terms of what is setting the pace, the price competitiveness of fossil fuels—and that includes soft coal from my State of Illinois—when one actually determines all of the costs in terms of health care and environmental damage and all of this, maybe we have got a few alternative energy sources right now that are a lot more price competitive than we think.

Do you know of any entity, any person that is making a study in this regard and really coming out with some statistics to point out that when you consider what we have to—all that we have to do to *repair the environment and lungs and black lung disease* and all that is the by-product of the burning of fossil fuels, there are—here are the energy alternative sources which A, B, and C are right now price competitive and we ought to be looking at, although in a free market economy maybe that is impossible.

Maybe we can't get there from here until such time as we see the ozone layer all gobbled up or our forests really being decimated much more so than others and find that there is genetic damage to the children and things of this sort.

Mr. MORRISON. Is the gentleman proposing a carbon tax? Since our friend from Texas has left, we can talk about this.

[Laughter.]

Mr. FAWELL. I am just one of these fellows who poses questions but doesn't have answers. But it seems to me that we are inundated with economists these days. They are more popular than lawyers and more abundant. There must be some conducting some surveys on this.

Mr. WOLF. Let me respond to several points you raised.

One, I think what I call the efficiency industry, the new lights, the new motors, the new furnaces, it does compete and it is more cost effective than traditional fossil fuel supplies. I think that is one of the reasons the economy from 1973 to 1986 grew by 40 percent but our energy use only went up 3 percent. I think that there are significant differences and it is important for the committee to recognize between the market for energy efficiency products and the alternative energy sources.

Energy efficiency right now frequently will beat hands down traditional fossil fuel generation. It is one of the reasons in the Northeast and elsewhere in the country electric utilities are promoting demand side management programs, why they are giving you rebates to install new air conditioners, because it is cheaper than the new fossil fuel sources. They will give you rebates to insulate your home. Why factories can take advantage of purchasing variable speed drive motors. It is cheaper to put in a new General Electric variable speed drive motor than to purchase the electricity from the utility.

So I think the economics are very favorable, frankly, for a lot of the energy efficiency technologies that are out there on the market. In fact, the potential is still vast compared to what we have begun to tap.

To address your question about the externalities and environmental externalities, several of the public service commissions as part of what they call their least cost planning process are asking utilities when they file their plans to consider the environmental externalities associated with the production, and you can look at hydro power as an externality and a coal plant might have another.

For example, I held up one of the new compact fluorescent bulbs, which was invented at LBL National Laboratory, and I said this is not a light bulb, but this bulb is 200 pounds of coal. Over the lifetime of that bulb it will save burning 200 pounds of coal, and that

is an environmental benefit as well as a direct consumer benefit in terms of cheaper energy bills.

Mr. FAWELL. I like also your idea that the government, with regard to its purchasing policies, ought to be hip deep in this program and making very sure that they set the pace.

To your knowledge, has the government ever really embraced that concept, a concept like that?

It is a new and novel idea to me, but maybe it is not new to anybody else in this room.

Mr. WOLF. Unfortunately, they haven't, and in part it is because of the bureaucratic structure, where the federal energy management program tries to do a good job but the General Services Administration is the one that does most of the purchasing.

Senator Wirth, who is the chairman of the Alliance at the current, with Senator Heinz as the co-chairman, has been trying to get the Architect of the Capitol to install energy efficient lighting in the Capitol.

So I can encourage this committee to get involved in that effort as well.

Mr. FAWELL. Thank you very much.

Dr. OTTE. Mr. Fawell, may I address a philosophical question?

I am deeply troubled. I have spent my whole life in the energy sector, first in oil and gas and in the last 20 years in geothermal. I also believe in a market-oriented economy and a marketplace, but for the government—I think it is right for the government to have an energy policy and to sort of buy a certain technology and buy resources.

We have been blessed in this country that we had a lot of oil and gas traditionally and that we have a certain degree of independence. But would it be acceptable for us, as one of the leading free enterprise nations and the lead democracy in the world, to—if we had to import all of our liquid hydrocarbons? Would that be right from a strategic point of view?

And I think if we had to, I think there have to be—I think somebody had to ask himself. We don't think for a moment that our defense industries are all free market oriented. They come sponsored by the Defense Department, and I think an energy policy on which the total economy is dependent, to leave that completely to the free marketplace troubles me, and certainly now that we overlay certain environmental concerns on that, global warming. We don't know the impact of some of these matters.

I think it is definitely, I think, the place of government to bias it and to direct it in an area of national need and national security and national economy, and it is for you gentlemen and the Administration to take the lead on that, and I guess that is what you are trying to do to a certain extent, and I applaud your efforts, and I think we have not seen enough of that in the last couple of years, I fear.

Mr. FAWELL. Thank you.

Mr. STALLINGS. Dr. Otte, I certainly agree, I think if there is a criticism of the previous Administration, it would have been the lack of an energy policy, and I think the wisdom of the chairman of the full Science and Technology Committee and this Energy Sub-

committee has done about as much to fill that vacuum as any committee on the Hill.

So I am very pleased with the efforts that we have made here. As one of the junior members, I have looked to the leadership from this committee, and I think it has done a very good job.

We are hopeful that this next Administration will do a better job of setting the national energy centers for us and try to develop an energy plan because it certainly has been lacking in the previous Administration.

We appreciate you gentlemen's time and testimony. We would hope that you would be amenable to additional questions if you receive them from this committee.

[Witnesses excused.]

Mr. STALLINGS. Our final panel, Earl Kelly, Director, Governmental Affairs, American Wind Energy Association, and Mr. Robert Noun, Solar Energy Research Institute.

If you gentlemen would take your seats at the table.

Gentlemen, we welcome you to the subcommittee.

Mr. Kelly, if you would go first, and then we will have you follow, Mr. Noun, and then if you are amenable to questions, we would appreciate it.

STATEMENT OF MR. EARL KELLY, DIRECTOR, GOVERNMENT AFFAIRS, AMERICAN WIND ENERGY ASSOCIATION

Mr. KELLY. I am Earl Kelly, the Director of Government Affairs for the American Wind Energy Association. I have been with the Association now only a few months, but it is very encouraging today to hear the support from the subcommittee, and we know that wind energy and all renewables have had the subcommittee's support in the past. But we hope that there is, shall we say, a rebirth in interest in these renewables.

We of the Wind Industry Association strongly endorse H.R. 1216, the Renewable Energy and Energy Efficiency Technology Competitiveness Act of 1989. We urge the subcommittee to approve this important legislation.

There are three—and I am going to keep my testimony very short—but there are three broad, but very valid policy reasons that wind energy and the other renewable sources of energy should receive the support as set forth in H.R. 1216.

One is, as we have heard, energy security. It just is mind-boggling to me how much longer we as a nation are going to continue consuming expensive imported oil, and when I say expensive, maybe not necessarily in the per barrel price, as Mr. Fawell was just asking, but the overall cost of energy consumption.

The way it is working right now with Mr. Sharp's office, in the Office of Technology Assessment we are working to have a study conducted of the overall costs for energy production and consumption by type of energy. There is a West German study that was just released last year showing in that country the cost of production and consumption.

When these costs of production and consumption are all taken into consideration, we feel that wind energy especially and all renewable energies will look very good because in the case of wind

energy, for example, right now we produce electricity at 7 to 9 cents per kilowatt-hour and there is no pollution to clean up afterwards. There is no reclaiming from mining. There is just no pollution as a result.

Another thing relating to energy security that I would like to point out is the short installation time between the time, say, a wind farm receives its permits and the time that we can start producing electricity. We can have components of that total wind farm in place and producing within six months from the time the permits are approved.

One more point I would point out about energy security is up to 40 percent of today's electricity demand in the United States can be met by wind energy. The wind resources are available in this country that would generate that much electricity, and we recognize as a feasible matter there are some transmission lines difficulties; for example, where the winds are great, the local market for electricity may not be so great, and we understand that and we readily admit it, but at least theoretically the wind exists in this country for up to 40 percent of our energy demands.

So I think H.R. 1216 deserves everyone's support based on energy security.

I think another policy area is export trade. The world's market for renewable energy technology is growing, and it is growing fast. Market analysts estimate that by the year 2000 the market worldwide will be 3- to $6 billion per year for renewable energy technology, and that is a lot of money.

And one reason for this is that we go back to the incremental installation that is available, whether it is wind or solar or whatever type of system you are looking at. A lot of developing nations cannot afford to suddenly go in and build a large nuclear facility or a large hydro facility, or what have you. They can purchase in smaller increments the renewable technology, and therefore there is a growing demand for this technology.

Furthermore, once the purchases are put in place the fuel costs are zero, and that is rather appealing to a lot of countries. We seem to be one of the few that do not regard purchasing fuel as significant, but they will be energy secure, some of the smaller countries, before we are, I anticipate.

The third and final policy reason I think 1216 deserves our support deals with environmental problems, and I would just cite just a few quick facts about wind energy and its impact on the environment.

Currently, there are about 16,000 commercial sized wind turbines operating in the United States. Each year each one of these machines on an average prevents the emission of 9,110 pounds of sulfur oxides, 2,803 pounds of nitrogen oxides, and 175 pounds of particulates. That is each year each machine offsets that much pollution if certain grades of coal, for example, are used as a fuel, and that varies again with the type of emissions, the pollutants that we are preventing from being dumped into the air. It varies with the type of fuel used, but that is just one statistic that I would point out.

So I think fully for environmental reasons wind and the other renewables deserve consideration, and I think one of the best and

most important steps to giving these sources of energy, clean sources of energy, the support that they need would be passage of H.R. 1216.

And I thank you very much.

[The prepared statement of Mr. Kelly follows.]

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Testimony of

Earl Kelly, Director of Government Affairs

AMERICAN WIND ENERGY ASSOCIATION

Concerning H.R. 1216
The Renewable Energy and Energy Efficiency
Technology Competitiveness Act of 1989

Before The

Subcommittee on Energy Research and Development

Of The

House Committee on Science, Space, and Technology

May 23, 1989

1730 N. Lynn Street, Suite 610, Arlington, VA 22209 USA Tel. (703) 276-8334 Telex 6503304640 MCI UW

Madam Chairman and Members of the Subcommittee:

On behalf of the American Wind Energy Association (AWEA) and its members, I would like to thank you for the opportunity to testify on H.R. 1216, the Renewable Energy and Energy Efficiency Technology Competitiveness Act of 1989.

AWEA is a trade association which represents wind turbine manufacturers, component suppliers, developers, electric utilities, and other companies around the nation. Founded in 1974, AWEA develops technical standards for wind-powered electric generating equipment.

There are now about 16,000 commercial wind turbines in the United States with an installed capacity of approximately 1,500 megawatts. In 1988, our industry generated about 1.8 billion kilowatt hours, a sum sufficient to meet the annual residential needs of Washington, D.C.

Despite its substantial capabilities, the wind energy industry in the United States is at a critical juncture. We face strong competition from abroad, particularly from Europe and Japan. Governments in Europe are undertaking ambitious R&D programs of their own and planning to build the next generation of wind turbine. It would be no small irony if the United States, which led the industrialized world in developing wind technology in the 1980s, became dependent on imported turbines in the 1990s.

We believe we can avoid that scenario, but it will take a partnership of government and industry working together in order for our industry to remain a viable force in the international marketplace in the next decade. H.R. 1216 helps achieve those goals, and we strongly endorse this legislation.

In the testimony that follows, I will attempt to address five key issues relating to the legislation: 1) the multi-year authorization levels; 2) the opportunities to improve efficiency and reduce the cost of wind turbines; 3) the joint venture provisions in the bill; 4) the contribution that wind energy can make toward alleviating our nation's air pollution problems; and 5) the issue of international competitiveness.

1. The need for multi-year authorization levels and adequate annual appropriations.

In the 1970s, after the OPEC oil embargo, the U.S. Department of Energy initiated an ambitious research and development program in wind energy that put the United States — its national laboratories and industry — in the international vanguard of wind technology.

Department of Energy funds for wind energy perform a vital function: the department and the national laboratories conduct technical and economic studies that are on the forefront of aerodynamics, structural dynamics, advanced components and other supporting research. From these studies the commercial industry obtains a better understanding of loads imposed on a machine and the designs needed to build more cost-effective and reliable turbines.

The wind energy program, however, has been cut substantially in the last nine years. We are now at the point where fiscal 1989 appropriations are approximately one-eighth of what they were in fiscal 1981. The figures below document the decrease in federal R&D funds for wind.

Federal Appropriations for Wind R&D

Fiscal 1981:	$83.7 million
1982	34.7 million
1983:	31.4 million
1984:	26.5 million
1985:	29.1 million
1986:	24.8 million
1987:	16.7 million
1988:	8.6 million
1989:	8.8 million

The proposed fiscal 1990 budget calls for appropriation levels of $8.35 million, yet another reduction.

AWEA believes that multi-year authorizations and adequate appropriations are necessary for the industry to regain its leadership in the increasingly-competitive international marketplace. Multi-year authorization levels help provide stability and continuity to federal R&D program; they allow the DOE to undertake R&D projects extending over several years with the confidence that these efforts will not be discontinued in mid-stream.

We support the three-year authorization provisions of H.R. 1216 because they allow DOE to undertake new R&D initiatives in wind energy with some degree of confidence that these programs will continue in the 1990s.

2. Improving efficiency and reducing the cost of wind turbines.

Since the early 1980s, the cost of installing a wind turbine for a wind farm has decreased from about $1,500 to $900 per kilowatt. Meanwhile, the performance of the machines has improved steadily. Availability, a measure of the time a turbine is available to generate electricity, has increased from about 70% in the early 1980s to about 97% in the best wind farms. Capacity factors have increased steadily too, and the most productive wind farms now have capacity factors of between 25% and 33%.

Despite this progress, our industry needs to do better if we are to expand our market and become more competitive. The cost and performance of these wind turbines in many parts of the country is still not competitive with coal-fired generation nor with oil or gas at current prices.

The next step, AWEA believes, is to build the next generation of machine, an advanced wind turbine with improved performance that can generate electricity at lower costs. The joint venture provisions of H.R. 1216 help industry meet that

goal because they allow the private sector and the DOE to cooperate on specific R&D projects such as the advanced wind turbine.

3. The joint venture provisions of H.R. 1216.

If H.R. 1216 were enacted, AWEA believes that building an advanced wind turbine should be the top priority for a joint venture R&D project involving our technology. As envisioned by AWEA, this wind turbine development initiative would be a four-year program that would result in the design and construction of prototype machines by the mid-1990s.

The proposed advanced wind turbine would be in the intermediate size (probably in the 200-500 kW category) and would incorporate major advances in turbine design and operation.

The wind turbine would offer three distinct advantages: 1) it would operate economically in lower wind speeds; 2) it would generate electricity at a cost of about 5 cents per kilowatt hour, compared with current costs of 7-9 cents per kWh; 3) it would be larger and more efficient than most commercial machines on the market, thus reducing overall life-cycle costs.

We believe the industry is ready to undertake successfully such a joint venture. There are numerous engineering and consulting firms, utilities, developers, and other companies with sufficient background and finances to serve as partners with the DOE in this venture.

Although AWEA cannot say for sure which firms would bid on such a joint venture partnership, we would like to call to the Subcommittee's attention the entrance of several utilities, including Virginia Power, into the wind field. The entrance of these firms is a positive sign; it shows that companies with a track record of project development are serious about investing in wind turbine technology.

4. The greenhouse effect.

In recent months, there has been much discussion in the scientific community and Congress about the build-up of carbon dioxide and other gases that appear to contribute to the "greenhouse effect" and changes in global climate.

Wind energy can help alleviate these and other problems relating to air quality. The electricity our industry produces is clean: there are no emissions and no waste. Each installed wind turbine displaces large quantities of pollutants. If the wind turbine offsets a mixture of oil and gas, it avoids the emission of an estimated 595 pounds of sulfur oxides, 368 pounds of nitrogen oxides, and 84 pounds of particulates each year. If the turbine offsets coal, it avoids the emission of estimated 9,100 pounds of sulfur oxides, 2,800 pounds of nitrogen oxides, and 175 pounds of particulates each year.

How much of an impact can wind energy reasonably be expected to have in the

future? Probably the most realistic assessment was offered by the Department of Energy in 1987 in its Energy Security report. In that document, the DOE estimated that by 1995, annual energy production could reach 10 billion kilowatt hours (about five times current production), and by 2005, it could reach 70 billion kilowatt hours (about 35 times current production).

Capturing more energy from the wind is theoretically possible, and several studies have attempted to quantify wind's maximum contribution. Those reports, prepared in the mid-1970s by DOE consultants, estimated that as much as one trillion kilowatt hours could eventually be generated from wind turbines if multi-megawatt machines were installed throughout the United States.

Although AWEA does not expect that wind turbines will produce that quantity of our nation's energy supply in the near future, the industry can help significantly to alleviate our nation's environmental problems.

There are excellent, undeveloped wind resources in the Panhandle of Oklahoma and Texas, in parts of Wyoming and Montana, and in mountain ranges on the East Coast, including in West Virginia where Virginia Power has proposed building a wind turbine test facility. Developing wind farms in these parts of the country would also create local jobs and help diversify our nation's energy supply at a time when foreign imports are increasing.

One often-neglected attribute of wind energy is the speed with which the industry can install large-scale wind farms. In 1984, for example, developers installed approximately 400 megawatts of turbine capacity. Similar quantities were installed in 1985. These 800 megawatts -- equivalent in size to a medium-size coal facility -- were installed in just twenty-four months, a rapid response time when compared with the lengthy lead time needed for many conventional sources.

5. International competitiveness.

In the last nine years, while the U.S. cut its federal R&D budget, other industrialized countries have been increasing their research efforts in this field. Danish and Japanese firms have entered the U.S. marketplace in recent years with newer and larger machines, and foreign machines now account for approximately 50% of all the turbines installed in the last four years in the United States. If this trend continues, the U.S. is in serious danger of losing the competitive advantage it has held to foreign manufacturers, many of them supported directly or indirectly by their national governments.

One of the largest markets for U.S. technology is abroad, particularly in developing countries. A federal interagency group, The Committee on Renewable Energy, Commerce, and Trade (CORECT), has played a key role in funding trade missions, market assessments, and other projects designed to give more visibility to renewable energy technologies in developing countries. The proposed Administration budget for CORECT, however, calls for a 50% cut in fiscal 1990 from $1 million to $500,000. H.R. 1216 attempts to address part of the problem by providing stable authorizations for these valuable export activities.

7. Conclusion.

Our industry cannot remain competitive if the U.S. government does not support wind technology with stable authorizations and appropriations for research, development, and international activities.

In recent years, we have seen our technology and jobs go overseas. H.R. 1216 helps reverse this trend. It provides multi-year authorizations for the federal renewable energy program, sets realistic performance standards for the DOE research efforts, requires the DOE to form joint venture R&D projects with the private sector, and increases the assistance for those federal agencies that help market U.S. renewable energy technologies all help our industry.

We urge the Subcommittee on Energy and Power to approve this important legislation.

Thank you, Madam Chairman, for giving us the opportunity to testify before this Subcommittee. That concludes my testimony, and I would be glad to address questions about the wind energy industry in the United States or our position on H.R. 1216.

Mr. STALLINGS. Thank you, Mr. Kelly.
Mr. Noun.

STATEMENT OF MR. ROBERT NOUN, MANAGER, DEVELOPMENT AND COMMUNICATIONS OFFICE, SOLAR ENERGY RESEARCH INSTITUTE

Mr. NOUN. Thank you, Mr. Chairman.

The Solar Energy Research Institute has been before this Committee often in the past. We have been able to come here, I think, regularly and report both on the progress and prospects for all of the renewable energy technologies. We are here to do the same today, to put it in the context of our support, with some minor reservations, of H.R. 1216.

We believe this bill reestablishes clearly a firm national commitment to renewable energy and energy efficiency and should help bring back needed stability into the program.

The question arises why should we continue with our commitment, and as you can see in my written statement here, we think that the technologies have continued to make extraordinary progress in almost every respect, and I won't go into detail. You can see that in the testimony.

Just a couple of things that I might highlight for you.

In the last year alone, as you can see, the DOE program- related research set almost two dozen new photovoltaic efficiency records. With the new thin film technology and manufacturing economies of scale that we think are achievable now, the cost of photovoltaic electricity should soon drop, we believe, to in the neighborhood of 12 cents per kilowatt-hour.

In the biofuels area, there are exciting things going on there as well. Just as an example, in the last year improvements in our fast pyrolysis, the process to derive gasoline from biomass, has reduced the projected cost of biocrude gasoline from about $2 per gallon to about $1.60 per gallon.

And finally, I will just mention that in our own institute, SERI's genetically engineered enzymes, the xylose isomerase, has helped reduce the cost of wood-derived ethanol to about $1.20 per gallon. This reflects about a 70 percent drop in cost reduction over the last 10 years.

So again we can go on and look at some of the advances that are being made in the technologies in a research and development sense as well as some of the market aspects that we have heard about previously.

I might also mention, in addition to contributions made by the technologies to our energy supply needs, we are now finding, for example, that concentrated solar energy can be used—and this was referred to earlier—for more than creating heat or generating electricity. It can also be used to destroy hazardous wastes, and we think there are several advantages to some of the work that we are doing in the high flux solar research, and you can find more detail about that in the written statement.

I am not going to address markets of renewable energy technologies other than to say—because they have been addressed already—just to give you just my own personal experience about a

year ago, having traveled to Guatemala on one of the CORECT trade missions, representing SERI on that mission.

We found in terms of bulk power markets in that part of the world—and I think many of you are aware that there is a major conference coming up in a couple of weeks in Miami, Energy in the Americas—the Guatemalan government, the Cerezo government has a very ambitious rural electrification program underway. They are very excited about using solar technologies. In fact, there is PV and wind projects that are being experimented with currently in Guatemala. So we think that that market has some real potential.

Now, let me move ahead and just mention, since this subject has come up a couple of times today, our view on how renewable technologies can help mitigate the buildup of greenhouse gases, and I think it is instructive to note that both the International Energy Agency and EPA have recently suggested that renewable energy may be the best option for stabilizing the accumulation of greenhouse gases.

The energy mix under the Office of Technology Policy projections for the year 2010 adds credence to this, since it indicates that U.S. carbon emissions will likely increase by as much as 40 percent by that time, exacerbating the greenhouse effect.

It is our view at SERI and elsewhere that by incorporating more renewable energy and energy efficient technologies that the U.S. could reduce its carbon emissions by in the neighborhood of 35 percent from the OTP projections at no extra cost to the economy.

So again a continued rationale for a strong or stronger commitment to work in this country on the renewable technologies.

Now, with respect to H.R. 1216, just a couple of comments.

SERI believes that appropriate cost shared joint ventures are beneficial to the renewable energy technologies and certainly to the industries that those technologies are striving to serve.

Our own experience—and there has been alot of it recently—demonstrates that well-designed cost shared ventures could help all of the parties to the deal—the research community, the industry players, and so on—form very effective and an integrated set of industry consortia, for example, that we have been pursuing at SERI and help us to compete internationally a good deal better than we are today.

We do have one concern with respect to cost-shared demonstration projects. We feel that those, if they are going to be used, must be carefully selected and crafted so that they don't jeopardize the funding for the basic research program, the underlying program, that we are all involved with.

Let me just give you one example of how we at SERI have been involved in what we think is perhaps the most direct and certainly the best method of technology transfer that is talked about under this bill.

One of our research projects in deriving liquid and gaseous fuels from biomass has nicely expanded into some other areas, including cost shared ventures that are currently being formed for producing adhesives for the forest products industry. What is the potential payoff here?

Well, it is significant just in the plywood and molding products alone. The phenolic content from these biomass produced adhesives

could save the—initially save the forest products industry about $30 million annually in feedstock costs, and again this is being set up as an industry/government consortium. There are a number of companies that have been attracted to it, including Boise Cascade, Borden Adhesives, Gaylord Chemicals, and others.

So I wanted to sort of throw that in as an example of how this can work, and we are excited about it as an approach.

Finally, I will just comment that in our view the stable and multi-year funding aspects of H.R. 1216 would clearly invigorate industry. You have heard that today. It would cause a resurgence in the technological and commercial development and enhance research, we think, at all levels, and bring stability to the federal renewable energy program, and we certainly all endorse that. So thank you.

[The prepared statement of Mr. Noun follows:]

Testimony of Robert Noun

Manager, Development and Communications Office
Solar Energy Research Institute

Before the
United States House of Representatives
Committee on Science, Space, and Technology
Subcommittee on Energy Research and Development

May 23, 1989

Abstract

In the testimony that follows, I make several points:

- Since H.R. 1216 reestablishes a firm national commitment to renewable energy and conservation, it is a bill I can support, with some reservations.
- The renewable energy technologies are continuing to make rapid progress, as evidenced by selected recent advances made in photovoltaics, biofuels, wind energy, ocean thermal energy conversion, and solar thermal.
- The markets for renewable energy technologies will continue to grow, first in specialty applications and then in the larger bulk power markets. Although we have witnessed ups and downs in the various emerging technologies, the long-term markets look very promising, with projections having renewable energy technologies supplying at least 12% of America's energy by 2010.
- According to the IEA and the EPA, renewable energy may present the world with its best option for mitigating the buildup of greenhouse gases. In the United States, with strong government leadership, renewable energy could help cut the expected carbon emissions by 40% or more.
- The stable, multi-year funding that H.R. 1216 represents should benefit both the program and SERI.
- Cost-shared joint ventures and demonstration projects can serve a useful purpose in advancing the research and in spurring the adoption of renewable technologies. However, we understand the concern that such efforts could be detrimental to the overall renewable program and might absorb a disproportionate share of available funding.

H.R. 1216 — a Welcome Bill

This bill reestablishes a firm national commitment to renewable energy and conservation and should help bring stability back into the program.

I congratulate the Subcommittee on fashioning a bill that has the right ingredients — a bill that I can support, with few reservations. In these times of fiscal conservatism, you have put together a bill that addresses renewable energy and energy efficiency in a manner which seems to me to recognize and be consistent with their increasing importance to the nation.

The bill reestablishes a firm national commitment to renewable energy and conservation and should help bring stability back into the program.

In addition to establishing more reasonable funding levels it also hits most of the other proper notes that make it a worthy bill. It sets national goals, which is a worthwhile exercise if we are careful to assure that the goals are both reasonable and obtainable. I would urge the Committee to work with the Department of Energy to assure that the timetables and goals established are consonant with the funding provided and ongoing programs.

The bill also recognizes the importance of both energy efficiency and renewable energy, for increasing America's energy self-sufficiency and for addressing growing environmental concerns such as the greenhouse effect. However, I think that the bill can be improved by providing more discretion to the Department of Energy in the selection, establishment, and termination of appropriate joint ventures.

I want the Subcommittee to realize that these are general comments showing my overall approbation of H.R. 1216. In the testimony that follows I will strike a few cautionary notes while answering the questions put to me in the letter inviting me to testify before the Subcommittee.

Renewable Energy Technologies are Making Rapid Progress

SERI has testified before House and Senate committees and subcommittees several times in each of the last few years. On several occasions SERI has reviewed in some detail how much progress the renewable energy technologies have made. So this year, in lieu of reciting the list of continuing and notable progress across the breadth of the renewable energy technologies under the national program, it may be more instructive to relate a few of the interesting and noteworthy advances that have occurred during the past year.

In the last year alone, program related research set almost two dozen new photovoltaic efficiency records.

Photovoltaics. Perhaps the most visible indicator of progress is the continued increase in efficiencies of the various photovoltaic materials and devices. Efficiency is important because the more efficient a device, the more sunlight is turned into useable electricity, and the cheaper that electricity becomes. Virtually every photovoltaic material, of which there are many, has seen dramatic increases in efficiency in the last dozen years. Devices made of thin-film materials, for example, have gone from less than 1% efficient to greater than 14% efficient. Even in the relatively mature technology of crystalline silicon, efficiency records

have nearly doubled, with some devices reaching past 29%. What is more, the progress in photovoltaics has been consistent. *In the last year alone*, program-related research set almost two dozen new efficiency records, amongst which was the crystalline silicon record just mentioned. A gallium arsenide multijunction device set the record for all materials and devices with an efficiency of nearly 31%. ARCO Solar, who has been perfecting its copper indium diselenide technology, set records for thin-film devices with a small cell that was almost 14% efficient and a square-foot module that was more than 11% efficient; many consider the module as an especially important breakthrough. In addition, just in the last couple of months, Energy Conversion Devices set an efficiency record for amorphous silicon modules and Chronar manufactured the largest amorphous silicon module ever — 12.5 square feet.

With new thin-film technology and manufacturing economies of scale, the cost of photovoltaic electricity should soon drop to about 12 cents per kilowatt-hour.

The Chronar module is part of their "Eureka" process, which will form the basis for a 10-megawatt per year manufacturing facility. This facility will provide modules for a planned 50-megawatt power station in California. With this capability, Chronar expects the cost of photovoltaic electricity to drop to about 12 cents per kilowatt-hour.

ARCO Solar intends to use its innovative copper indium diselenide technology to make modules that will also generate electricity for about 12 cents per kilowatt-hour. As with most of the advances in amorphous silicon, the copper indium diselenide technology that ARCO Solar is using was developed in conjunction with SERI and the National Photovoltaics Program.

Advances like these should enable American companies to wrest a large share of the burgeoning thin-film photovoltaic market from Japan, the current leader.

In the last year, improvements in fast pyrolysis has reduced the projected cost of biocrude gasoline from $2.00 per gallon to $1.60 per gallon.

Biofuels. Although there has been continuing progress in the many research areas that constitute the biofuels program, there are *three advances within the last year* that are particularly noteworthy. *First*, we have improved the process to derive gasoline from biomass by fast pyrolysis. We have done this by enhancing the catalyst used in the process for making gasoline from biocrude oil, resulted in higher yields of gasoline from biocrude and have combined to reduce the projected cost of the gasoline from $2.00 per gallon to $1.60 per gallon.

SERI's genetically engineered enzyme, xylose isomerize, has helped reduce the cost of wood derived ethanol to $1.20 per gallon, a 70% cost reduction over the last ten years.

Second, SERI is doing research that may help make ethanol, one of the most environmentally safe liquid fuels known, a primary transportation fuel. One of the best options for making ethanol is to derive it from woody crops and residues by first converting the wood into simple sugars and then fermenting those sugars into ethanol by yeast. However, as much as 30% of wood is hemicellulose, which may be broken down only into xylose, a sugar that yeast find difficult to metabolize. To overcome this problem, SERI researchers genetically engineered an enzyme, xylose isomerase, that converts xylose into xylulose, a readily fermentable sugar. During this last year, SERI's advances with this enzyme have increased the yield from xylose to 90% (up from 60%). This alone has reduced the cost of wood-derived ethanol from $1.35 per gallon to about $1.20 per gallon. (In ten years, researchers have thus reduced the cost by 70%, from $4.00 per gallon to $1.20 per gallon.)

With continued support for the efforts underway, SERI researchers believe they will soon be able to convert more than 90% of wood into ethanol, dropping the cost to less than 60 cents a gallon. And, by using other strategies such as converting the non-fermentable lignin in wood into octane enhancers for gasoline,

ethanol may eventually be produced for as little as 45 cents a gallon — this is equivalent to $20 a barrel oil.

Third, the DOE program has been investigating ways to turn municipal solid wastes (MSW) into useable fuels, such as methane. To derive methane from MSW requires anaerobic digestion, the degradation of the organic material in MSW by microbes in the absence of oxygen. During the last year, researchers have improved the anaerobic digestion process to where it now produces methane 6 to 7 times faster than before. Continued progress in research to derive useable fuels from MSW could eventually net the nation as much as 2 quads (equivalent to 344 million barrels of oil) of economical energy per year.

The new family of blades presently being installed on wind turbines in Southern California is a big step toward reducing wind-generated electricity to 4 cents per kilowatt-hour.

Wind Energy. *In the last year*, the Wind Energy Program installed newly designed air foils on some wind turbines in Southern California. These air foils are part of a family of new blade concepts that represent a major advance over those used on earlier generations of wind turbines. They are designed to satisfy the unique requirements of fixed-pitch, horizontal-axis wind turbines, which constitute the great majority of today's market. The new air foils are lighter, and are designed to last longer and to produce more energy. This development is a big step toward reducing wind-generated electricity to 4 cents a kilowatt-hour and thus making it competitive with electricity derived from any source.

As part of the effort to devise more efficient, longer lasting blades, the Solar Energy Research Institute set up a unique experiment to test blades and the stresses that occur under actual wind conditions. Previously, no one had taken highly accurate, simultaneous measurements of wind inflow, pressure, strain, and other characteristics on a horizontal-axis wind turbine and correlated them with power output. This comprehensive experiment will aid blade designers by producing a more complete picture of what happens during wind turbine operation.

With the advent of open-cycle systems, the promise of ocean thermal energy, especially for island communities, is becoming increasingly more enticing.

Ocean Thermal Energy Conversion. Until recently, ocean thermal energy conversion (OTEC) did not show great promise as an economical method for producing electricity for the future. But with the advent of open-cycle systems, the promise of ocean thermal energy, especially for island communities, became increasingly more enticing. This is partly because, in addition to electricity, an open-cycle system produces fresh water as a by-product. It is also because an open-cycle system requires cold ocean water brought up from the depths of the ocean, which is rich in nutrients and is the ideal medium for aquaculture.

But until *this last year* or so, the open-cycle concept was largely confined to theory. Now the concept is being tested in a large-scale system in Hawaii. The experiment is showing that open-cycle systems are technically feasible and that advances made in the SERI laboratory, such as the vertical spout evaporator, work under actual field conditions.

An interesting development is taking place at aquaculture farms near the experiment station. The National Program, along with the State of Hawaii, installed a cold water pipe that is bringing the cold, nutrient-filled water from the depths of the ocean to the surface. Here, entrepreneurs are using the water to cultivate lobsters and other sea-born delicacies. Profitable private industry has blossomed serendipitously from this national scientific experiment.

Concentrated solar energy can be used for more than creating heat or generating electricity. It can also be used to destroy hazardous wastes, process high value materials, and power lasers.

Solar Thermal. Since the solar thermal program began we have known that we can use the concentrated heat of the sun to produce electricity. This has been dramatically demonstrated by the 194 megawatts of solar thermal power installed by Luz, Ltd. in Southern California. This is presently the largest solar thermal power project in the world and Luz has plans to add hundreds of more megawatts.

In the last couple of years, however, program researchers have increasingly turned their attention to some equally beneficial applications of concentrated solar energy: hazardous waste destruction, materials processing, and solar lasers.

Using concentrated sunlight to *detoxify hazardous wastes* may offer advantages over conventional methods. One is that photon energy may enhance certain chemical reactions and thus detoxify some hazardous wastes much more effectively and at lower temperatures than standard combustion techniques, while saving energy in the process. Another advantage is that solar thermal systems can rapidly ramp up to temperatures in excess of 5400 degrees Fahrenheit, allowing us to destroy some wastes that other methods cannot. These advantages are being demonstrated by early experiments with photon enhancement, which show increased levels of destruction and reduced destruction times.

Another opportunity for the useful application for solar thermal technology is in the *surface treatment of advanced materials*. Sunlight concentrated more than 2000 times can be used to treat the surfaces of metals, ceramics, or carbon fibers to produce higher value materials. A solar furnace can be used to direct up to 80% of the concentrated sunlight energy onto the sample of the material. This is much more efficient than normal methods for treating materials. The direct concentration of sunlight on a surface holds the promise of significant economic advantage over the normal heat-to-electricity-to-light conversion chain.

Finally, solar thermal systems may be used for *solar pumped lasers*. Such a concept requires extremely high concentration ratios. Just over the past couple years researchers have developed two unique concentrator systems. One system achieves concentration ratios up to 65,000 suns while the other reaches past 50,000 suns. These achievements extend well beyond previous plateaus and bode well for the future use of solar powered lasers.

The Markets for Renewable Energy Technologies: We Win Some and We Lose Some

The developing nations may present the best intermediate-term markets because the renewable resource would be indigenous, and because their energy infrastructures are growing and are often widely dispersed.

Specialty Markets. For most of the emerging renewable energy technologies the near-term markets lie in specialized applications both at home and abroad. The developing nations may present the best intermediate-term markets because the renewable resource would be indigenous, and because their energy infrastructures are growing and are often widely dispersed.

Technologies that tap indigenous energy resources would enable developing nations to invest scarce financial resources in their own countries rather than drain already strained economies by paying foreign nations for their energy source. Also, because their infrastructures are growing, developing nations are likely to

be less intransigent to the introduction of new energy technologies. That their infrastructures are dispersed enables developing nations to accommodate the renewable energy technologies much better; some of the strongest selling points of renewable energy systems are that they are well suited for dispersed, modular, and remote applications. These characteristics also make renewable energy technologies ideally suited for specialty applications such as remote communications and other small-scale uses where they have already become extremely competitive.

During the past few years most developed countries have increased their support of renewable energy technologies while we have reduced ours.

Consider *photovoltaics*. Up until the early to mid 1980s, we saw the photovoltaic market for specialty applications climb substantially every year, with the U.S. owning more than 60% of the world market. By 1987 our portion of the world market had slumped to nearly 30%. What happened? In general, world shipments continued a steady rise, led by Japan with its efforts in targeting amorphous silicon thin-film products for the consumer markets. Japan's commitment to PV research and development soared past ours. The situation with Japan is not unique. During the past few years *most* developed countries have significantly increased their government involvement in and support of renewable energy technologies while we have been reducing ours.

America has also lost its once dominant share of the PV market because U.S. companies involved in renewable energy are generally young and small. In spite of the continuing technological progress, the U.S. industry lacks the vitality it needs to compete effectively in international markets. It is encouraging to see this bill addressing some of these issues.

We have confidence in the future of the photovoltaic markets; it is an exciting technology with a vast potential for growth. New advances will continue to be incorporated, manufacturing of scale will come into play, the cost of photovoltaic electricity will continue to decrease, and new markets will open up while old ones will grow.

Continued technological advances and long-term, stable support by the U.S. government could establish American companies on a strong foundation.

The same holds true for all of the emerging technologies. Continued technological advances will help open up specialty and international markets for dispersed applications. These, together with long-term, stable support by the U.S. government could establish American companies on a strong foundation, helping them not only in the primary applications of energy but also in the spinoff applications that occur. This, in turn, will help the technologies, and the companies, be ready to meet the larger challenge of producing energy for the bulk markets.

Bulk Power Markets. Although the specialty and dispersed markets are important to America's well being, the principal objective of the national renewable energy R&D program is to enable renewable energy systems to be substantially deployed in the American energy infrastructure and help America become energy self sufficient. We see this happening incrementally, both as a result of R&D in the emerging technologies and through other means such as increased awareness of renewable energy and laws like PURPA that give incentives for cogeneration. As a result, America is using more and more renewable energy.

In 1988, renewable energy supplied America with nearly 9% of its energy needs, 6.6 quads.

We have seen the use of renewable energy climb steadily from less than 3 quads in 1960, to 4 quads in 1970, to slightly more than 5 quads in 1980, to 6.6 quads in 1988. In relative amounts we have also seen the contribution of renewables climb to the point where they now provide enough energy to meet all of America's

energy needs for a month. Slightly less than half of this (3 quads) is coming from the mature technology of hydroelectric power. Almost another 3 quads is coming from the mature technology of the combustion of biomass. The rest is from the maturing and emerging technologies of geothermal energy, wind, photovoltaics, solar thermal, fuels from biomass, etc. The contribution from each of these, because the technologies are advancing steadily, is growing substantially. Over the last 15 years, for example, geothermal energy has grown by approximately 20 fold, to where it is supplying America with about one-fifth of a quad per year.

The amount that geothermal *is* contributing, however, is quite small compared to what it *could* contribute. Using today's technology, the U.S. could economically retrieve more than 8 quads per year — enough to meet about 10% of the nation's energy requirements. Moreover, given future technologies, we could retrieve considerably more than this. Partly because the resource is so enormous, the same may be claimed for *any* renewable energy technology. Given progress in the technologies, and some time to make them economical, we will be able to extract enough energy from direct sunlight and the sunlight energy stored in plants to meet all of America's energy needs, summer and winter, year after year.

Of course, some of those technologies are not yet here. But they are steadily arriving and are steadily becoming more economical. The DOE Office of Technology Policy (OTP) has, in a study of future energy use, taken the increasing promise of renewables into account. The OTP projects that by the year 2010 the renewable energy technologies will supply the United States with nearly twice as much energy as they do today — almost 13 quads, which would constitute about 12% of the 108.2 quads that America will consume by 2010.

SERI's analysis indicated that by 2010 renewable energy technologies could supply the United States with nearly three times as much energy as they do today — 19.5 quads.

Using the OTP figures as a starting point, SERI did its own analyses. One analysis assumed the government would provide incentives on such things as reducing greenhouse gases, and would thus encourage increased use of conservation and renewables. This analysis indicated that renewable energy technologies could supply the U.S. with as much as 19.5 quads of energy by the year 2010. Since this analysis assumed a strong conservation ethic, the total U.S. consumption would rise to only 92 quads of energy. Thus, renewables could provide our nation with 21% of its energy.

While some of the conclusions in these analyses vary, one major conclusion does not: the contribution from renewable energy technologies will grow significantly in the near future, both in relative and absolute terms. Not as readily apparent, however, is that the most rapid growth will occur in the emerging technologies. While hydroelectric power and the burning of wood and wastes may increase their contribution by as much as three more quads by 2010, the increase in energy from the emerging technologies should more than match this.

By the turn of the century, for example, photovoltaics could be adding more than 1 billion watts of capacity per year to the nation's power grid, and maybe as much to remote applications. By that time the cost of PV electricity will have dropped below 6 cents per kilowatt-hour, making it competitive with all currently known generating alternatives.

Some SERI scientists believe that the United States could produce between 130 billion and 260 billion gallons of ethanol per year, enough to run our entire transportation fleet.

There is also an enormous potential for gasoline additives and ethanol from wood, and for ethanol from other biomass. With further research and development, prices of ethanol from wood could decline to 60 cents a gallon within a decade. With these prices and with well-managed farms growing energy crops, and with

efficient use of MSW and agricultural wastes, some SERI scientists believe that the United States could produce between 130 billion and 260 billion gallons of ethanol per year. This is more than enough ethanol to run our entire transportation fleet. Of course, no one expects ethanol to penetrate the market soon on a scale that even approaches this magnitude.

Renewable Energy Can Help Mitigate the Buildup of Greenhouse Gases

Both the IEA and the EPA suggest that renewable energy may be the best option for stabilizing the accumulation of greenhouse gases.

Strong national and international leadership and initiative are apodeictic to reversing the trend of greenhouse gas buildup and stabilizing the atmosphere. But we also need wide ranging international cooperation on policies, standards, basic R&D, information sharing, resource analysis and development, financial packaging, and more. This is not just my opinion, it is the consensus of the experts who have just participated in an IEA (International Energy Agency) meeting in Paris on how renewable energy can help mitigate greenhouse gas buildup.

The IEA feels that the two best options for allaying the buildup of greenhouse gases are conservation and renewable energy. This consensus accords well with the draft report, *Policy Options for Stabilizing Global Climate*, from the Environmental Protection Agency (EPA), which goes even further to suggest that renewable energy may be the *best* option for stabilizing the accumulation of greenhouse gases, especially in the developing countries.

Both the IEA and the draft report from the EPA took a world view of this global problem. But a useful way for us to get a handle on how much renewable energy could help with the global situation is to consider the case of the United States. For this, we already have a reference point, namely the OTP projections of U.S. energy consumption. As mentioned earlier, the OTP study projects that in the year 2010 the United States will consume 108.2 quads. This is nearly 32 quads more than we consumed in 1986.

The energy mix under the OTP projections for 2010 indicates that U.S. carbon emissions will increase by a dramatic 38.6%, exacerbating the greenhouse effect.

Some of this increase will be due to consumption of renewable energy, which is forecasted to rise from the present 6.6 quads per year to 12.7 quads. But most of the increase will come from an increased use of fossil fuels: coal, oil, and gas. When burned, all of these fuels add carbon dioxide to the atmosphere, the primary greenhouse gas. Of these, coal produces the most carbon dioxide. The OTP predicts that the consumption of coal will increase the most, from 17.3 quads in 1986 to 36 quads in 2010. This, along with the increased use of gas and oil will drive U.S. carbon emissions up a dramatic 38.6%, from a present level of 1.32 billion tons of carbon to 1.83 billion tons. Obviously, the consumption of energy under this "business as usual" projection will exacerbate the greenhouse effect.

There are, however, things we can do to stem this trend. The preliminary analyses that SERI did (explained above) indicated several strategies we could adopt to mitigate the rise in carbon emissions, at no extra cost to our economy. First, we could adopt cost-effective conservation and energy efficiency technologies, such

as enacting efficiency standards for automobiles, appliances, and lighting. By increasing our energy efficiency sufficiently, by about 1.9% per year, we could reduce our expected energy consumption for the year 2010 to around 92 quads.

Second, we could displace 5 quads of coal with renewable energy sources like hydropower, biomass, geothermal, and MSW. And we could displace another 4 quads of coal with gas, which emits about half the carbon that coal does, per unit of energy.

Third, we could help produce and then import another 1.5 quads of Canadian hydropower.

Fourth, we could reforest federal lands and plant trees on one-half of the current inventory of crop set-aside lands. This strategy would fix an additional 3 quads of coal-related carbon emissions over a twenty year period.

By incorporating more renewable energy and conservation, planting trees, and importing more Canadian hydropower, the U.S. could reduce its carbon emissions by 35% from the OTP projections, at no extra cost to the economy.

These strategies would have renewable energy technologies supplying America with as much as 21% of its energy by the year 2010, a total of about 19.5 quads. All of these strategies together would result in carbon emissions of 1.19 billion tons. This is 640 million tons, or 35%, less than that entailed by the OTP projections. Moreover, we have to add to this the possibility of using conservation and renewable energy to practically eliminate the use of CFCs. And all of this is at no extra cost to the economy.

We must note that, like the OTP projections, the SERI analyses assumed economic neutrality, i.e. that renewables would have to be economically competitive with other technologies. It also assumed no major R&D or commercialization initiatives. It assumed government leadership would, (1) get organizations to switch to renewable energy wherever it made economic sense, (2) enact efficiency standards, and (3) promote greater use of hydroelectric power imported from Canada. It becomes apparent, then, that if the government also substantially increases its efforts in R&D, commercialization, setting stringent energy and environmental standards, and providing incentives and subsidies, the contribution from renewable energy technologies could accelerate even more.

Intensifying R&D would be an especially important strategy when considered in terms of the needs of developing countries. If the renewable technologies are not ready in time, the developing countries will turn increasingly to fossil fuels, most notably coal. The fossil fuels will then become an intransigent part of their energy infrastructure and renewable energy technologies will find it increasingly difficult to penetrate this market which, in terms of carbon emissions, will become the most important market in the world.

Reduced Federal Funding has Deleteriously Affected the Renewable Energy Program

Over the last eight years the funding for America's renewable energy program has been cut by more than 90%.

America's renewable energy program has suffered from funding cuts for each of the last 8 years. In the early 1980s the total funding for renewable energy was approximately $800 million. Since then the funding has fallen to less than $100 million, in current dollars. Considering inflation, this is a funding cut of more than 90%. Many of the initial cuts were appropriate. But the funding has ramped steadily down ever since. This does not seem appropriate for a national program for which there is such a clear need, which has made steady progress and from which the payoffs will be tremendous — abundant, domestically-controlled, pollution-free energy.

The initial cuts made us look more closely at the priorities and reconstruct a program that made more sense on the basis of long-term issues. We were able to come through this period and build a substantial foundation of research, create a solid core of scientific and technical personnel, and define reasonable, concrete goals.

Steadily declining funding has eroded the base we struggled long to build, hurt the program, and harmed SERI.

The years of steadily declining funding that followed, however, have eroded the base that we struggled long to build. This has harmed the program in general and SERI in particular. Since 1984, SERI has been struggling to maintain its critical mass and core scientific capability by using carry-over funding (GSO) remaining from its early years. SERI's funding has been approximately "level" for the past few years but at a level that is insufficient to maintain SERI's core scientific staff for the long term. If funding remains at present levels, SERI will have to continue laying off scientific staff. For example, the lay offs at SERI show how the problem is growing. Even with "level funding" we laid off 6 staff in FY85; 16 in FY86; 17 in FY87; and 23 in FY88. A modest increase in SERI funding will be needed just to maintain the Institute's current excellent scientific staff.

The decreasing amount of funding has at least three other harmful effects on R&D supported by the Institute. First, much of SERI's scientific equipment was purchased during the early years of 1980 and 1981. It is aging and needs to be updated and replaced, if SERI is to maintain its position as a world-class laboratory. State-of-the-art equipment is also important for retaining first-class scientific staff.

Second, to fund all of the deserving programs we have to "stretch" out the programs. That is, we have to slow them down. This approach is diametrically opposed to what is we should be doing, in light of such issues as climate change and acid rain. To address these issues properly, we need to bring the renewable energy technologies to market sooner, not later.

Third, SERI has operated for ten years now in rented office space that was converted into laboratories and meant only for temporary use. Clearly this is not as efficient, nor as safe, as operating in facilities designed to be laboratories.

Unstable funding has been harmful to industry and to the totality of America's effort in renewable energy.

As difficult as continued funding instability has been for SERI, it has been equally harmful to the industry and the totality of America's effort in renewable energy. The continued decline has done at least two things to America's renewable energy industry. First, shrinking funding and the disappearance of other types of support

have made it extremely difficult for the small, struggling solar energy businesses to survive. Second, a cloud of uncertainty has hung over America's commitment to renewable energy since the early 1980s. This has made industries, which otherwise may have been able to hang in for the long haul and make valuable contributions, wary of investing their valuable time, effort, and money in renewable energy.

Appropriate Cost-Shared Joint Ventures Would be Beneficial to the Renewable Energy Technologies

Well-designed cost-shared ventures could help research, industry, the markets, and our ability to compete internationally.

Speaking strictly from the perspective of a research organization, there are reasons why the government might be involved with industry in cost-shared ventures. First, the renewable energy industry is generally fragile and needs the impetus, in both R&D and scale-up, that government help would give them. Second, the market is generally slow and cost-shared ventures could help spur it. Third, international competition is tough, and if we are to remain competitive, we must find creative ways to offset the often heavy government support that some other countries (notably, Japan, Germany, Denmark, Sweden, etc.) lend to their industry.

However, we are also aware of difficulties experienced with joint ventures and understand the reluctance of some strong supporters of the program to favor such efforts, specifically in the current environment of constrained budgets. Research and development joint ventures is a broad term and includes research as well as demonstration projects. In some instances demonstration projects can prove useful: they can serve as a transition from the prototype phase to the commercial phase. They can help establish the feasibility of systems for commercial use. They can convince the public and interested parties of the utility of the systems. They can help increase potential investor confidence that they can get a return on their investment. And they can provide hands-on experience and valuable operation, maintenance, and resource information. To accomplish all this, however, demonstration projects must be carefully considered, diligently planned, appropriately timed, and terminated promptly when program objectives have been achieved.

If we cost-share demonstration projects, we must be careful that they don't interfere with the funding of the rest of the renewable energy program.

But there is a danger in placing too much emphasis on demonstration projects. For one, if we push a technology into demonstration before it is ready, we will convince industry that the technology itself is not worthy, and will thus make it more difficult to bring the technology into the infrastructure once it is technically ready. Also, demonstration projects can be extremely expensive and time consuming. So emphasizing them, could siphon resources from important R&D avenues or other cost-shared research projects that could advance the technology faster and more soundly. In light of this, if we consider demonstration projects as cost-shared ventures, it is important for the program and for America's effort in renewable energy to fund such projects as an *addition* to the program rather than as part of normal program funding. Otherwise, the scarce funds will devolve to the demonstration projects and the basic R&D programs will be left with less funding than presently.

The kinds of joint ventures that would do the most good for the country are those that would add to our knowledge base — scientific and technological — take the research from proof-of-concept phase into the more applied and practical phases, and that would help manufacturers overcome basic stumbling blocks on their way toward commercialization. These are the kinds of joint ventures where government managers and researchers would form partnerships directly with the industries that would commercialize the product. These are also the kind that can prove to be very serendipitous, where research in one direction leads to leveraging that research through cost-shared results in another, spinoff, direction.

One of our research projects in deriving liquid and gaseous fuels from biomass has expanded into other areas, including cost-shared ventures for producing adhesives for the forest products industry, benefitting both industry and research into renewables and conservation.

We presently have several such joint ventures. One instructive example is our research in the pyrolysis of biomass. Pyrolysis is a process in which biomass is rapidly heated in the absence of oxygen and the complex molecules in biomass materials or wastes are broken down. In this process, which is very similar to cracking in the petroleum industry, useful products, such as crude oil, can be drawn off at various points in the reaction process. SERI scientists recognized the potential of this method and started investigating different products. Beginning with liquid and gaseous fuels, the research expanded to include cost-shared research in adhesives and other valuable by-products for the wood products industry.

Liquid and Gaseous Fuels. Early in the 1980s, SERI researchers started developing a unique vortex reactor that allowed the biomass cracking process to proceed with a rapid transfer of heat and short reaction times. The primary intention of this process was to produce crude oil for use as a boiler fuel and to produce olefins, which could be converted into gasoline. In 1986, these engineers and scientists studied the basic principles involved and combined the pyrolysis process with catalytic conversion to produce aromatic gasoline, a blending stock used by petroleum companies to make high octane gas.

The private sector became very interested in these concepts. Currently, Pyrotech (Kansas) is scaling up the vortex reactor for the purpose of generating boiler fuels. Pyrotech, with SERI providing technical expertise under a collaborative agreement, is building units that will be able to process 35 tons of biomass per day. They will install their first units at the Samoa (CA) site of Louisiana Pacific, a forest products company dedicated to becoming energy self-sufficient at all of its 128 plants.

Mobil Oil Corporation is interested in the catalytic process to produce aromatic gasoline. Aromatics, used as octane enhancers, are valuable and scarce and will become increasingly so as we phase lead out of our gasoline.

Unfortunately, since the research on aromatics is not very mature, we have not yet reached the point where it is economically competitive with the conventional petroleum process. The critical step in achieving this is to scale-up the reactor and test it. Our researchers are following an innovative path for doing this. The question they asked is: why just work on scale-up? Why not, rather, have your scale-up efforts pay off by resulting in useful products that are a natural outcome of the scale-up process? In answer, they decided to test the reactor by investigating an application that was in perfect accord with the scale-up: adhesives from the pyrolysis of biomass. These adhesives, they recognized, could become economically competitive in a relatively short time frame, thus sweetening the transition toward the economic reduction of aromatics.

Adhesives. SERI scientists, and the team of experts they assembled from academia and industry are investigating ways to use the vortex reactor to pyrolyze waste sawdust or bark into phenolic resin. These resins, which currently are derived from petroleum, are used by the forest products industry as adhesives for wood paneling, plywood, molding, other board products, and insulation. In 1987 the United States produced about 2.6 billion pounds of these resins at an average cost of 50 cents per pound.

In plywood and molding products alone, phenols from biomass could initially save the forest products industry $30 million annually in feedstock costs.

After 18 months of investigation, the research team developed formulations of pyrolysis oils that could replace 50% of the phenol in the molding compounds and plywood adhesives. Moreover, they project that the cost of the phenol derived from sawdust or bark could be as little as 10 cents to 16 cents a pound, or even less. Replacing 30% of the petroleum-derived phenols could save our nation almost a tenth of a quad (equivalent to 17 million barrels of oil) of energy per year by 2010. Plus, in plywood and molding products alone, phenols from biomass could initially save the forest products industry $30 million annually in feedstock costs. All of this with a relatively small R&D investment from the government.

It is potential like this that has attracted a host of interested companies, many of whom have been directly involved since the beginning of this program either through research or through an industrial review board. Interested private sector parties include the American Plywood Association, Boise Cascade, Borden Adhesives, Gaylord Chemicals, Georgia Pacific, Koppers Co., Perkins Industries, E. Seidel and Associates, and Weyerhaeuser Co.

Adequate, Stable, Multi-Year Funding will Benefit Renewable Energy Research

H.R. 1216 asserts the need for stable funding levels, which are important for bringing renewable energy toward its potential.

H.R. 1216 is a positive signal from the Congress of a strong commitment to renewable energy. This bill asserts the need for stable funding levels, which are important for bringing renewable energy toward its potential.

Adequate, stable, multi-year funding would invigorate industry, instigate a resurgence in technological and commercial development, enhance research on all levels, and bring stability to the federal renewable energy program.

Adequate, stable, multi-year funding would help reinvigorate industry's interest in renewable energy and thus instigate a resurgence of both technological and commercial development. It would also help the R&D effort at SERI. Under the stability that would follow, SERI would be better able to plan research. The Institute could reemphasize some programs and revitalize others. It could retain top-quality researchers and professionals and attract others. Staff morale would climb. SERI could maintain its position as the world's leading center for renewable energy research. Research would accelerate and results would come forth more quickly.

Much of this is very general. So it may be more instructive to point out how stable, multi-year funding could help in just one of our research disciplines — biofuels.

Biofuels is a broad research area with great promise and a wide set of technologies. Through the biofuels technologies we will be able to derive heat,

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electricity, chemicals, pharmaceuticals, liquid fuels for transportation, food, lightweight plastics, and more, without adding to greenhouse gases or to acid rain.

Adequate, stable, multi-year funding would better enable us to develop enzymes, microbes, and bacteria we need to produce liquid and gaseous fuels from wood, herbaceous crops, and agricultural and municipal wastes. It would help us accelerate other work, such as developing better methods of fermentation, genetically engineering new organism strains, discovering new and better ways to cultivate energy crops, enhancing anaerobic digestion, designing reactor systems for gasification, and developing algal strains (which not only would produce oil, but would fix large quantities of carbon).

We could equally accelerate our programs in biofuels conservation technologies where, for example, we are investigating ways to make lightweight, inexpensive plastics from biomass. One especially important use for such lightweight material is in automobiles. Another use, which comes from our ability to make biodegradable plastics, is in polystyrene packaging for fast-food chains. Developing these plastics not only would help our nation conserve energy but would also enable us to more wisely utilize our biomass feedstock and help us eliminate another source of CFCs.

We could also accelerate and expand our investigations on synthetic photosynthesis — an avenue of research that Nobel Laureate Sir George Porter believes could answer all of our energy and food needs in the future. Or, we could increase our program on using biotechnology to make adhesives for the plywood industry. Or we could explore many ways in which to produce hydrogen from biofuels, sunlight, and water; hydrogen is an energy vector that is facile as an energy transport or storage medium, or as the "ultimate" transportation fuel.

Adequate, stable, multi-year funding would allow us to accelerate and broaden our research programs, pursue multiple research paths, and produce results more quickly.

Finally, we could put greater emphasis on our program for deriving ethanol from wood and wastes. This could help us more quickly reduce the cost of ethanol to 60 cents, or even 45 cents, per gallon.

These examples give you an idea about what we could do in biofuels. What we could accomplish with adequate, stable, multi-year funding in biofuels, however, we could do equally well in all of our other programs. We could broaden all of the programs, continue to pursue multiple paths, and produce results more quickly.

Mr. STALLINGS. Thank you, Mr. Noun.

Mr. Morrison, would you like to pose any questions?

Mr. MORRISON. Just to Mr. Kelly. We have had some excellent presentations. Mr. Noun from SERI. In fact, for a number of years we have been proud of what you are doing.

In the wind area, though, Mr. Kelly—and I realize that you are new to the Association—we spent a lot of money through the years, particularly on some larger machines, and now your proposal that the area that we need for research and demonstration, intermediate, smaller type machine, what leads us to that conclusion?

Mr. KELLY. What we look at, sir, is the per kilowatt-hour cost of the machine, and right now the commercial machines on the market are at about 900 to 1000, $1100 per kilowatt, installed, and the machine of this very large size and because we know that the 3.5, I believe, megawatt machine in Hawaii—those are excellent research projects, but we do not feel that they have at this time commercial application due to their initial cost.

The machines that we are proposing, on the other hand, would be somewhat larger than the average machine being made today. The average now is about 100 to 120 kilowatt-hours, and we are proposing an increase to 200 to 500. So it is a substantially larger machine that we are proposing be built than the average one today.

At the same time, I think I am referring to the same type of machine that you mentioned, sir. Those just—for example, the maintenance of them. If you have even a minor problem with a machine that size, it becomes a major production to repair it. The time that it can take to set up cranes to lift the parts are so large, and the machines that we are using now in a commercial manner and that we are suggesting be built are not so large and are not so expensive.

Mr. MORRISON. Is the conclusion then that you would rather, say, establish a farm where you had a number of smaller units and then they collectively provide the base of energy that you would need at a specific location?

Mr. KELLY. Yes, sir. That seems by far to be the preferable route to go. Wind technology—at least with the materials that we have today and the weights of those materials, et cetera, wind technology does not lend itself to building vast machines. That one machine, for example, would generate 3.5 megawatts. We would suggest a number of smaller machines would be much more economic and more reliable.

Mr. MORRISON. And this legislation in front of us you feel gives your Association the flexibility to perform your part of the action?

Mr. KELLY. Yes, sir. This legislation, 1216, under the requirements for the areas of wind R&D is basically mandating what we refer to in the trade as the advanced turbine. It is a little larger size than we have now. It has got more sophisticated electronics, variable speed generators, improved air foils.

So in other words, the people in my particular industry writing the design specs, they would look an awful lot like the language in 1216, and I think this bill sets forth what is needed in the industry at this time.

Mr. MORRISON. Thank you very much.

Mr. STALLINGS. Mr. Fawell.

Mr. FAWELL. Again, just a comment. When you mentioned up to 40 percent of the energy demands of the nation theoretically could be met, but you admit that transmission lines and things of that sort would have to come into play, and I couldn't help but think of superconductivity and if and when that would be perfected, then you could transport it without loss and it should be quite a boon to the potential of wind as a source of energy.

Mr. KELLY. Yes, sir. Anything that can improve the conductivity will be.

Mr. FAWELL. I have a lot of ignorance on this subject. So what I will say will betray it, I suppose, but if we think in terms of an industrial park or an area—I think of windmills out on the farms and things of that nature where electricity was generated, and so forth—but this is not feasible, I gather, from what you have indicated, say, for an industrial park to have wind-generated—just for that particular park? That can be supplemental at least to a traditional electricity source?

Mr. KELLY. Sir, actually that is feasible, and we get a number of inquiries and we have a number—they are not in the business of generating electricity for commercial purposes. They are wanting for their own industry. People are interested in using wind, and many of them are beginning to purchase equipment for that, for that usage.

Mr. FAWELL. I don't see any of that. Wouldn't I see a windmill or something that is used to catch the wind? Is something like that being done, for instance, in the Chicago area?

Mr. KELLY. I honestly cannot answer.

Mr. FAWELL. It is a windy city, you know.

[Laughter.]

Mr. KELLY. One reason we don't encourage their use around urban areas is the safety factor. Should something go wrong, we would hate to see someone hurt.

We do know that particular industry—schools, for example—Massachusetts has a number of schools that are using wind powered turbines to cut down on their electricity bills. In the Southwest, Texas, Oklahoma, a number of industries are using wind powered turbines to cut their costs.

One thing we are trying to do, we are trying to encourage the Department of Defense to utilize wind turbines on their fixed facilities, even if not in remote locations. I understand there are technical reasons that the military may not prefer wind turbines on some of their remote facilities, but on their fixed facilities; for example, in Oklahoma. There are excellent wind resources there.

Mr. FAWELL. Thank you to both of you. We appreciate your testimony.

Mr. STALLINGS. Let me ask one question of both of you. Would you give us your opinion on the provision to provide 30 percent cost sharing by the private sector that is included in this legislation?

Mr. NOUN. I will give you a series of opinions based on our experience with that, Mr. Chairman.

We have entered into cooperative research agreements now for several years. In fact, our wind research program at SERI has entered into about 12 such agreements, and what we have done is, in

issuing a request for proposals to enter into research projects with us, we make as a criteria the amount of cost sharing that the industry partner is willing to bring to the table; 30 percent to 50 percent, as was mentioned earlier, tends to be the average, but we have seen several that have hit 50 percent. I am not sure that every—I am not sure how you look at a required minimum, but everybody understands that it is expected when we go out for these types of cooperative ventures.

Mr. STALLINGS. Mr. Kelly.

Mr. KELLY. 30 percent up to 50 percent, the range we have discussed, will no doubt prohibit a number of our members from participating—they are small—if it is a cash payment method of participation. There might be some other ways that they can meet the value of that and still participate.

But I can fully appreciate the need for the—shall we say the admissions price to be somewhat substantial because you want companies involved, you want the private sector involved that is capable of delivering its share, also, not only of money but of expertise and goods.

So I think overall I would have to say that we have no difficulty with the 30 percent requirement.

Mr. STALLINGS. Thank you.

Mr. Morrison or Mr. Fawell, anything else you would like to ask this panel?

[No response.]

Mr. STALLINGS. Gentlemen, we thank you for your participation. This has been a most enlightening session, and with that I guess the hearing is closed until further notice.

[Whereupon, at 4:00 p.m., the subcommittee was adjourned subject to the call of the Chair.]

APPENDIX I

OPENING STATEMENT
BY U.S. REP. JERRY COSTELLO
COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY
SUBCOMMITTEE ON ENERGY RESEARCH AND DEVELOPMENT
MAY 23, 1989
"RENEWABLE ENERGY AND ENERGY EFFICIENCY TECHNOLOGY COMPETITIVENESS ACT OF 1989"

This subcommittee today will address one of the most crucial topics facing our country today. Recent reports detailing the high increase of our dependence on foreign oil points to the need to have a comprehensive energy policy that relies on more domestic fuel production, but also alternative energy sources, including renewable energy and implementing greater energy efficiency standards.

Today's legislation will attempt to focus on the need for greater federal funding for renewable research and development of energy research programs. The issues of global warming and the greenhouse effect pose some serious problems for the United States.

Exploring these energy options are crucial for maintaining a sufficient level of energy safety and alternatives for our country. I look forward to today's hearing on this important legislation.

APPENDIX II

GEOTHERMAL ENERGY TECHNOLOGY: ISSUES, R&D NEEDS, AND COOPERATIVE ARRANGEMENTS

Prepared by the
Committee on Geothermal Energy Technology
Energy Engineering Board
Commission on Engineering and Technical Systems
National Research Council

NATIONAL ACADEMY PRESS
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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Frank Press is president of the National Academy of Sciences.

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The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an advisor to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Samuel O. Thier is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public and the Institute of Medicine. Dr. Frank Press and Dr. Robert White are chairman and vice-chairman, respectively, of the National Research Council.

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PREFACE

With some assurance, it is anticipated that the long-term trend in U.S. petroleum reserves and production will be one of decline. The low cost of petroleum in 1987 has resulted in a decline of U.S. oil production and exploration. Consequently, petroleum imports will likely increase over the next 10 years. Coal is attractive because of large U.S. reserves, but its use would have significant environmental effects if cost-effective, clean, coal-burning technologies are not developed. Even with reduced sulfur and nitrogen oxide emissions, coal combustion--like combustion of other fossil fuels--adds carbon dioxide to the atmosphere, possibly causing climatic changes and global warming. Though more than 100 U.S. nuclear power plants provide a significant fraction of the nation's electricity, we have no assurance that additional nuclear power plants will be built here. Given these uncertainties about future energy supply, continuing the development of various energy technologies that may become commercial is necessary. One geothermal energy technology is already commercial in the United States, and other forms of the technology are possible energy sources.

The study leading to this report responded to a request to the National Research Council's Energy Engineering Board by the Department of Energy's (DOE) Geothermal Energy Technology Program. The main study tasks were to review the DOE geothermal program, identify principal issues in the geothermal energy field, and suggest possible cooperative arrangements among government, industry, and universities to facilitate research and development (see Appendix A). The Committee on Geothermal Energy Technology, formed in 1986, first met in December 1986. At this meeting, Dr. John E. Mock, DOE's Geothermal Technology Program director, briefed the committee. A workshop and meeting on February 9 to 11, 1987 (see Appendix B) focused on geothermal energy research and development and on related cooperative arrangements. The committee drafted its report in a working session.

The committee thanks Dennis Miller, former Director of the Energy Engineering Board, for his development of the study; Dr. James J. Zucchetto, Senior Program Officer, for his useful management and support in all study phases and for preparation of the final report from the rough drafts of the committee; and all workshop participants who provided valuable information and analysis. Heartfelt thanks also go to Drusilla Alston for her administrative support.

Norman Hackerman
Chairman

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EXECUTIVE SUMMARY

In 1986, the National Research Council, through its Energy Engineering Board, formed the Committee on Geothermal Energy Technology. The committee's study, sponsored by the Department of Energy's (DOE) Geothermal Technology Program, addressed major issues in geothermal energy technology, made recommendations for research and development (R&D), and considered cooperative arrangements among government, industry, and universities to facilitate R&D under current severe budget constraints.

Funding for the Geothermal Technology Program has decreased from a high of about $158 million in fiscal year 1979 to $21 million in fiscal year 1987. In addition, current (1986-87) low petroleum prices have led to stagnation of the U.S. geothermal industry. These low prices have affected development of alternative technologies, such as for solar energy use and for conservation, and have led to a decrease in domestic petroleum production. Decreased production will most likely increase dependence of the U.S. economy on petroleum imports over the next decade. The committee believed that the current low prices of hydrocarbon fuels, especially of petroleum, is a short-term phenomenon within a long-term trend toward rising prices driven by a rising demand and limited supply of lower-cost resources. Given this scenario, it is necessary for the United States to maintain some energy supply options over the coming decades, many of which are now only marginally economic. Because of the large U.S. geothermal energy base, and the possibility of converting even a small part of this resource into economically useful energy, the committee concluded that the development of U.S. geothermal resources at competitive prices could be an important contribution to U.S. energy self-sufficiency.

The report addresses four types of geothermal energy: hydrothermal, geopressured, hot dry rock, and magma systems. Hydrothermal systems are the only type that are now economically competitive commercially. Further technology development by DOE could make the uneconomical hydrothermal resources commercially attractive to industry. The economics are more uncertain for the longer-term technologies for extracting energy from geopressured, hot dry rock, and magma systems. For some sites, the cost of energy derived from geopressured and hot dry rock systems is projected within a commercially competitive range. The use of magma energy is too far in the future to make reasonable economic calculations.

For geothermal energy, the location of the resource critically affects the economics. Isolated geothermal fields distant from areas of demand probably cannot be exploited economically. Advances in transmission line technology (such as by using high-temperature superconducting materials) may remove this constraint.

Many environmental effects of hydrothermal systems are judged either to have been solved with environmental control technology or at least to be amenable to solution. Potential environmental problems for geothermal energy use include the possibility of land subsidence from the use of geopressured reservoirs, the disposal of hazardous fluids, and the initiation of microseismic activity from injecting fluids in wells. Using geothermal rather than fossil fuel plants would reduce atmospheric loading from oxides of nitrogen and sulfur, carbon dioxide, and particulates. In most cases, such institutional factors as permitting, leasing laws, regulation, and tax treatment would not present insurmountable barriers to geothermal development.

The committee generally agrees with the Geothermal Technology Program goal: to determine and improve the scientific, engineering, and economic feasibility of using energy from hydrothermal, geopressured, hot dry rock, and magma geothermal resources. Developing hydrothermal resources should receive near-term emphasis by both government and private industry. The technologies developed for this resource will help in developing the longer-term resources of geopressured, hot dry rock, and magma systems.

Significant budget decreases over the last few years in the Geothermal Technology Program have severely affected many R&D projects. The committee concluded that a somewhat higher and much more stable level of funding is required to accomplish further commercialization of many hydrothermal resources in the near term and to maintain a viable research program for the longer-term resources (see Chapter 2 and Table 2-5).

Many types of cooperative R&D efforts among government, industry, and universities were examined by the committee. For geothermal energy development, private industry is currently interested only in investing in the near-term hydrothermal resources, many of which are already commercial and economic. Development of the longer-term resources of geopressured, hot dry rock, and magma systems requires federal funding.

Given the existing state of the geothermal industry and energy economics in the United States, one model of cooperation between government and industry stands out as the most successful approach to short-term geothermal R&D. This is the cooperative arrangement between the Geothermal Drilling Organization (GDO) and DOE. Its aim is to develop technologies that in the short term will reduce costs for collecting data on (logging), drilling, and completing geothermal wells. The committee recommended that the GDO be restructured and broadened to address a wide range of short- to mid-term geothermal development activities, and be called the Geothermal Development Organization.

For the longer-term geopressured, hot dry rock, and magma resources, in which industry is not investing, the committee recommended that a Geothermal Research Organization (GRO) be established. It would be a cooperative university and government endeavor, composed of researchers interested in the scientific and technical issues of long-term geothermal

resources. Industry participation would not be required but would be encouraged. The GRO would help coordinate the relatively small number of academic researchers working on these long-term resources and the large number of scientists working in allied fields. Informal contacts between the Geothermal Development Organization and the GRO could be maintained through observers at each other's meetings.

1

TECHNICAL SUMMARY

The current worldwide oversupply and low cost of fossil fuel energy have contributed to a significant decline in funding U.S. Department of Energy (DOE) research and development (R&D) on alternative energy technologies. Affected by this decline in particular is R&D in geothermal energy technologies. Further, as a direct result of lower fuel prices, private development of geothermal resources has stagnated.

The Committee on Geothermal Energy Technology addressed a number of specific tasks relevant to these issues (see Statement of Task, Appendix A), partially through a workshop to which experts were invited (see Appendix B). This report reviews U.S. geothermal energy goals and DOE's Geothermal Energy Technology Program (GTP), identifies major issues for U.S. geothermal energy R&D, and suggests approaches for cooperative arrangements among government, industry, and the universities to increase the effectiveness of GTP's limited budget. This chapter summarizes the report, including major conclusions and recommendations. Chapter 2 briefly describes geothermal energy resources, addresses issues for each type of geothermal energy, and considers required DOE R&D funding levels for each. Chapter 3 addresses cooperative arrangements among government, industry, and universities for identifying possible new funding approaches for the GTP.

THE U.S. ENERGY SITUATION AND GEOTHERMAL RESOURCES

In general, there is demand for energy of different types, reflected by the market, and there are long-term national needs that cannot be assessed through considering existing supply/demand conditions because supply can change discontinuously and because national objectives include more than assurance that supply and demand are in good balance. Meeting national needs, such as long-term energy security, requires appropriate government involvement. Long-range energy research in many different areas must be pursued for the nation to respond to and solve its energy problems. Solutions require R&D supported by government and the private sector on various resources and technologies, including those that are not yet economic.

The committee seriously considered the low market price of petroleum during 1986-87 and its apparent oversupply in world markets. The committee agreed that the low petroleum price during this period was (1) transitory and would eventually rise, (2) depressing the petroleum industry and domestic petroleum production, and (3) increasing U.S. dependence on imported petroleum. Consequently, the nation could suffer an energy crisis in the not too distant future. In addition, low petroleum prices have lessened the economic attractiveness of alternative energy technologies and their development. The geothermal energy industry in the United States has stagnated, and budget cuts at DOE have led to significant declines in the GTP (e.g., from a total budget of $158 million in fiscal year 1979 to $21 million in fiscal year 1987 [see Chapter 2, especially Table 2-1]).

The resource base for geothermal energy is large. But how much of this resource base can be economically converted into useful energy is uncertain. Given the large amount of energy associated with the resource, the ability to convert even 0.1 percent of the resource into an economically competitive energy form would represent an important contribution to the U.S. energy supply. This report addresses four types of geothermal resources: (1) hydrothermal systems, consisting of accumulations of either water or steam in porous or fractured rocks; (2) geopressured systems with anomalously high fluid pressures below 4,500 m depth; (3) hot dry rock systems, rocks of such low permeability that they are described as "dry"; and (4) magma systems, in which lava is contained in a chamber beneath a volcano. Hydrothermal resources are the most developed, have the greatest application, and are economically competitive. In 1986, all the world's geothermal electric power used either steam or hot water from hydrothermal systems. Of a total world installed capacity of 4,733 MWe (megawatts electric), more than one-third (1,788 MWe) was operating in one field, The Geysers, in Sonoma and Lake Counties, California. Almost all the high- and intermediate-temperature geothermal resources occur in the western states of Alaska, California, Hawaii, Idaho, Nevada, New Mexico, Oregon, Utah, and Washington. However, low-temperature resources, which can potentially be used for space heating and low-temperature industrial applications, occur in these states and elsewhere in the central and eastern states.

Conversion technologies for power generation from hydrothermal systems using dry steam systems, single or multiple flash cycles, and binary cycles are all operating commercially. Given present costs for oil and gas, the generation costs for new capacity at The Geysers are competitive with those of petroleum, coal, and nuclear power plants. However, for other hydrothermal systems to compete, the prices of petroleum and gas would have to be near those of 1985. DOE could accelerate the commercialization of hydrothermal resources that are currently uneconomic. Present economics of geopressured, hot dry rock, and magma systems are too

unfavorable in the near term to attract any industry involvement. If these resources are to be developed, DOE must pursue R&D of these riskier geothermal energy types as a long-term activity having potentially high returns when the costs of competing energy sources escalate.

COSTS OF GEOTHERMAL POWER

The economics of geothermal power production have been evaluated for many situations. At the busbar (the power plant switchyard), the cost of electricity from geothermal energy is a function of the reliability of the reservoir and power plant operating as a unit plus the cost of energy. For power plants operating in remote regions, the cost of electricity transmission is also a factor. Technological developments can obviously lower these costs. Vapor-dominated hydrothermal resources are used for power production, and they are economically competitive. Liquid-dominated hydrothermal systems promise to be within the range of the current competitive price of electricity, namely, 50 to 70 mills/kWh (5 to 7 cents/kWh). In addition, many hydrothermal systems are near the economic threshold, so every improvement in technology will make them more attractive. The economic uncertainty of geopressured resources hinges on variations in both the recoverable volume and rate of recovery from the producing sandstone formation. At sites that have large volumes and flow rates, electricity costs are projected at about 60 mills/kWh for systems that use chemical (methane), hydraulic, and thermal energy. Estimated costs of producing electricity from hot dry rock vary significantly with rock temperature, well depth, and reservoir productivity. For example, assuming reasonable rates of fluid production, the Fenton Hill, New Mexico, site is projected to produce electricity in a commercially competitive range. Too little is known about magma energy resources and technology development to make any reliable economic estimates.

NONPRICE CONSTRAINTS

Several technological constraints require R&D to remove these barriers to commercialization. Important technical problems include reservoir characterization, chemical corrosion, drilling, limited availability of lower-cost high-temperature materials, and conversion technologies (see Chapter 2 and Appendix D).

In the early development of geothermal energy extraction and conversion in the United States, there were some serious environmental concerns, for example, about hydrogen sulfide releases and excessive noise. These problems have been solved to an acceptable degree. But others remain, such as the possibility of land subsidence from exploiting geopressured reservoirs, the disposal of hazardous geothermal fluids, and the initiation of microseismic activity from injecting fluids into the ground. With the use of hypersaline solutions, the most costly environmental problem facing industry is land disposal of solid wastes that in some cases are considered hazardous. All these problems depend on the site, the particular technologies used, and the prevailing regulatory

situation. Issues in land use and aesthetics also vary, depending on the site. However, these issues should be placed in perspective. Other kinds of power plants also affect the environment and land use. Fossil fuel power plants are allegedley significant contributors to the problems of acid rain and may be the source of potential global climate change from atmospheric pollutants generated from fossil fuel combustion. Nuclear power plants entail the risk (real or perceived) of potential release of radionuclides. Geothermal power plants would reduce or eliminate these environmental problems associated with fossil and nuclear power plants.

Each of the geothermal resource types tends to be found in certain areas of the United States. If the demand for the energy produced from a given site is not within an economically acceptable distance, the site may not be developed. In the case of heating systems, too great a distance will result in an unacceptably high loss of heat. For electric power, the availability of transmission lines is important because transmission losses over long distances are significant. This last constraint may be reduced through technological developments in superconducting materials, which have just been demonstrated at temperatures around 100 K (-173°C), above that of liquid nitrogen.

Current institutional factors--permitting, leasing laws, regulations, and tax treatment--are not insurmountable barriers to geothermal development, except perhaps in special cases. Of course, these factors might be addressed in such a way that they are made more helpful to geothermal development.

THE DOE GEOTHERMAL ENERGY TECHNOLOGY PROGRAM

The committee generally agreed with the goal of DOE's Geothermal Technology Program, determining and improving the scientific, engineering, and economic feasibility of using energy from all types of geothermal resources, including hydrothermal, geopressured, hot dry rock (HDR), and magma. HDR R&D dominates the current budget, accounting for 38 percent of it; geopressured and hydrothermal research account for 19 and 14 percent, respectively. Only about 6.7 percent ($1.4 million) was directed for drilling technology, which cuts across all geothermal technologies.

Development of hydrothermal energy resources, the most technically and economically feasible to exploit, should receive near-term emphasis by both government and private industry. The short-term goal of R&D should be to achieve technical improvements in locating, developing, extracting, managing, and converting energy from liquid-dominated hydrothermal reservoirs. These improvements should markedly increase the number of U.S. hydrothermal reservoirs that can be used to produce energy in the near term. At the same time, these technologies are needed to exploit geopressured, HDR, and magma resources commercially, and they are fundamental subjects for a balanced DOE R&D program. The longer-term goal of the R&D effort should be to determine whether geopressured, HDR, and magma energy resources are a feasible option for the future and to provide a technical base for industry's evaluation of their commercial use (specific research for each geothermal resource is delineated in Chapter 2).

The budget of the GTP has declined from about $158 million for fiscal year 1979 to less than $21 million for fiscal year 1987 (see Chapter 2, especially Table 2-1). Funding for the major areas of R&D continues, but the reduced hydrothermal research budget affects important projects significantly. Given both the potential for commercializing hydrothermal energy in the near term and the need to maintain a research program for longer-term resources, a somewhat higher and stable budget is needed. Stable DOE funding is important to attract and maintain the qualified technical staffs required to develop the technology.

COOPERATIVE ARRANGEMENTS

Most of the workshop was devoted to examining cooperative R&D efforts among government, universities, and industry (see Appendix B) in presentations from invited guests and discussions with an advisory group. Given present constrained federal budgets and increased economic competition from abroad, cooperative arrangements should be considered as one mechanism to enhance R&D productivity, attract funds to given programs, and increase U.S. economic competitiveness. The Statement of Task (see Appendix A) directed the committee to examine two scenarios for cooperation, one based on the existing DOE program and the other on a program the committee recommended. Differences between these two programs would not affect the nature of cooperative arrangements in any significant way; thus, such a scenario analysis was not considered relevant. However, given the higher budget levels the committee recommended, somewhat more money would be available from industry to participate in hydrothermal research.

Cooperative arrangements among industry, government, and universities have been around for many decades, and they exist in literally thousands of variations, but they may not always be desirable. The committee reviewed several types of cooperative arrangements and examined existing arrangements such as the Microelectronics and Computer Corporation, the Electric Power Research Institute, and the Gas Research Institute. One type of arrangement is industry-industry cooperation, in which the sources of funds and the primary beneficiary of the research are industry. A second type is industry-university cooperation. Three basic approaches exist: (1) an "industry affiliates" program in which a number of companies pay modest fees to support limited research programs; (2) industry contracts with universities for specified research; and (3) companies forming a corporation to support university research. A third type of arrangement is government-university cooperation, ranging from the support of large laboratories to small contract investigations. A fourth type is government-industry cooperation, such as through government contracts with single companies and arrangements between government agencies and consortia of companies. Further, government-industry-university cooperation is the most complicated, but perhaps the most effective for matters of national importance, which generally require significant outside funding.

The committee reviewed these alternatives, taking into account the present economics of energy in the United States, the impact of current

economics on the geothermal industry, and recent changes in tax laws. One model, an example of government-industry cooperation, stood out as an especially successful approach to short-term geothermal R&D. This is the existing cooperative agreement between the Geothermal Drilling Organization (GDO) and DOE. GDO is open to all organizations and individuals who pay a membership fee. The present objective of GDO is to develop technology that in the short term will reduce costs for drilling, completing, and logging geothermal wells. GDO generally sets research priorities and seeks funding from its members and DOE.

Industry will continue to invest only in near-term exploitable hydrothermal resources. Because hot dry rock, geopressured, and magma energy resources require extensive development and their profitability is too far in the future, industry is not investing in them. However, because of the importance of maintaining various future energy options, R&D on long-term geothermal resources should be continued. To accomplish this goal, a cooperative relationship could be established through a Geothermal Research Organization (GRO) composed of researchers interested in the scientific and technological issues of long-term geothermal resources. Industry participation in this organization would not be required but should be encouraged. GRO would provide advice to government agencies, develop a research agenda, establish a contract administrator to disburse funds from the government (and private industry if interest developed), and form a Geothermal Coordination Group, which would transfer information between GDO and GRO and speak for the broader interests of those involved in geothermal R&D. Otherwise, coordination between the GDO and GRO would be informal, possibly through sharing a member or sending observers to each other's meetings.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

- The current oversupply and relatively low prices of hydrocarbon fuels, especially petroleum, are short-term fluctuations within a long-term supply shortage. Given the large U.S. geothermal energy resource base and the potential for converting even a small percentage of this base into economically useful energy, developing U.S. geothermal resources may be an important contribution to U.S. energy self-sufficiency.
- In the short term, private industry will continue to invest in technologies for exploiting hydrothermal resources. It will not invest in development for the longer-term resources of geopressured, hot dry rock, and magma energy. Because maintaining various energy supply options is critical, a viable and stable research program for these longer-term geothermal energy resources is necessary.
- In the near term, hydrothermal geothermal resources will be used more than other geothermal resource types. Improving technologies for use should make many of the presently uneconomic resources competitive. Power production from geopressured and hot dry rock resources is potentially favorable for some sites, although using these resources is a longer-term

possibility. Magma energy technologies are too uncertain now to make any reasonable economic projections.

- o Significant strides in environmental controls for hydrothermal energy systems have been made since their early development. There has not been enough operating experience on other types of geothermal systems. Environmental problems remain, but they are site-specific and are thought to be remediable through appropriate study, engineering design, and construction practices.
- o The geographical distribution of geothermal energy resource fields is a constraint to geothermal energy use, one that could be alleviated by advances in superconducting materials and their use in electrical transmission lines.
- o Institutional barriers are not a major constraint to geothermal energy development.
- o Stable and adequately funded DOE R&D is needed to determine and improve the scientific, engineering, and economic feasibility of using energy from all types of geothermal resources. The short-term emphasis should be on hydrothermal systems and methods to facilitate their more rapid development.
- o Long-term R&D should be directed toward determination of the viability of geopressured, hot dry rock, and magma energy resources for future energy production. Expenditures in these areas can decrease as commercial viability is proved or disproved and industry begins to participate as projects are terminated.
- o The existing GDO is one successful model of cooperation, which is judged to be the best cooperative approach to short-term R&D related to drilling, given current energy economics and the state of the U.S. geothermal energy industry.
- o The GDO model can and should be modified to address the wide range of short- through mid-term cooperative geothermal development activities.

Recommendations

- o The DOE Geothermal Program should be funded at a somewhat higher and stable level (see Chapter 2, especially Table 2-5) to maintain viable R&D programs for both near- and long-term geothermal resources. The funding recommended for each geothermal resource category is at a critical minimum level; it would decline over the period as anticipated research goals are met (see Tables 2-2 to 2-4).

- o The charter of the GDO should be expanded from its current coverage of "geothermal drilling" to "short- to mid-term geothermal development." The GDO's name should be changed to the Geothermal Development Organization and a restructuring implemented.

- o A Geothermal Research Organization should be formed, composed of researchers interested in the scientific and technological issues in developing long-term geothermal energy resources: geopressured, hot dry rock, and magma energy. This organization would serve as an excellent means of coordinating the relatively small number of academic researchers working on these long-term resources and the large number of scientists working in allied fields.

2

ISSUES, R&D NEEDS, AND THE DOE PROGRAM

GENERAL CONSIDERATIONS

Geothermal energy derives from the natural heat of the earth. Where natural conditions concentrate this heat, energy can be extracted and converted to either thermal or electrical energy to meet demand. Potentially exploitable geothermal resources exhibit a considerable range of thermodynamic, hydrological, and geological conditions; they are classified as: hydrothermal, geopressured geothermal, hot dry rock (HDR), or magma energy resources. Hydrothermal geothermal resources are usually divided into two subtypes: (1) vapor-dominated fields, where dry steam exists in fractures, solution channels, and cavities in the reservoir rock and (2) liquid-dominated fields, where a fractured porous reservoir is saturated with hot water.

The Resource Base and U.S. Energy Supply

The U.S. geothermal energy resource base is large and widespread, offering a potentially important contribution to the U.S. energy supply. Current estimates place the total accessible energy in place from all four types of geothermal energy at greater than 1.2×10^6 quadrillion Btu (quads) (Muffler or USGS, 1979). The most favorable hydrothermal systems for power generation (the only type commercially developed) lie in the western states, including Alaska, as do most HDR and accessible magma deposits. However, other forms of geothermal energy are also found in most areas of the country. Low-temperature systems are available for direct heat applications in at least 30 states, and large geopressured geothermal resources are located along the Gulf of Mexico and the Pacific west coast and in Appalachia and various deep sedimentary basins (Muffler, 1979).

The energy recoverable from this geothermal resource base is uncertain, but it is estimated at approximately 4.5 percent of the 1.2 million quads, or 55,700 quads (Muffler or USGS, 1979). Such energy, the equivalent of 90,000 oil fields the size of Prudhoe Bay, is large in light of the U.S. annual energy consumption of 80 quads per year. Thus, geothermal energy might provide 600 to 700 years of the total U.S. energy requirement.

Presently, only a fraction of this recoverable resource base can be produced at prices that are competitive with other energy sources. However, the fields under development in California, Nevada, Oregon, and Utah have the capacity for producing more than 10,000 MWe (megawatts electric) for 30 years according to U.S. Geological Survey (USGS) estimates.

Geothermal energy can become even more important as the costs of other energy sources rise, because the current worldwide oversupply in hydrocarbon fuels is only a short-term phenomenon occurring within a long-term supply shortage. U.S. petroleum production is projected to decline from 11 million barrels per day (mbd) in 1985 to about 8 or 9 mbd in 1995, a decrease of 18 to 27 percent (DOE, 1987). The result will be a sharp rise in petroleum imports, primarily from the Middle East, unless domestic production increases. In addition, petroleum and natural gas industry capital expenditures for exploration and development have dropped 50 percent since 1981 (Hirsch, 1987).

Though a number of advantages can accrue from developing U.S. geothermal resources, the potential contribution of these resources to domestic energy production is certainly one of the most important. Geothermal energy is inherently a secure domestic source of energy that can reduce U.S. vulnerability to international forces. In addition, use of the small-scale modular geothermal power plants now available permits a fast reaction to either petroleum shortages or changes in electricity demand.

Geothermal energy, available continuously, is a baseload alternative to conventional fossil fuel and nuclear power plants. Given favorable economic circumstances, geothermal resources can be a reliable substitute for competing fuels. For existing geothermal power plants, availability factors are commonly higher than 95 percent, in contrast to U.S. averages of 78.7 percent for fossil fuel plants and 65.2 percent for nuclear plants (based on statistics from 1974 to 1983 of the North American Reliability Council).

Development of geothermal resources, then, presents important advantages for the United States. Development can proceed in two ways. Industry and government can let short-term market forces dictate a reduced development effort, or the present period of grace with low oil prices can be used to prepare for the next anticipated energy shortage.

Economic Issues and Projected Costs

Estimating the economics of energy extraction for the four geothermal energy resource types varies greatly, given their different stages of

development. Even so, the general cost relationships delineated for hydrothermal energy use in Figure 2-1 are applicable to other geothermal resources.

In today's market, to compete with conventional sources of electric power generation, the cost of power must be within the range of 50 to 70 mills/kWh (5 to 7 cents/kWh), the current range for electrical power produced from fossil fuels. Electric power from the vapor-dominated hydrothermal system at The Geysers, the only known vapor-dominated system in the United States, is competitive today. The least expensive liquid-dominated hydrothermal systems are expected to produce electricity at about 60 mills/kWh, and a substantial fraction of hydrothermal resources is near the economic threshold.

The other types of geothermal resources are not commercial. Cost estimates and projections for each of the four types of resources are discussed in separate sections of this chapter.

The Utilities' Perspective

The commercial viability of geothermal generation for utilities is largely determined by the cost of generating and delivering the electric energy to the customer and by the power generation alternatives that may be available. Underlying both factors, of course, is the question of how much generating capacity, including new capacity, is needed.

Need Utilities will not actively pursue new geothermal hydrothermal power plants if their projections of load and capacity growth do not demonstrate the need for new capacity. In addition, utilities are presently striving to avoid projects that require new capital. Most western utilities are projecting a need for new capacity in the mid-1990s. All these factors have slowed U.S. geothermal development in the immediate future.

Cost of Energy To ensure the greatest market penetration, the cost of the geothermal energy must be as low as possible, consistent with achieving the required reliability of supply. Aside from inflation, the major factors affecting energy cost at the busbar (the power plant switchyard) are reliability of the plant and reservoir operating as a unit and the cost of the energy.

Another factor affecting the cost of energy delivered to the customer is transmission. Many geothermal resources are located in fairly remote areas, removed from the centers of electricity consumption. Bulk transmission lines are usually not near to these resources. If they are, uncommitted transmission capacity in these lines may not be available. Advances in high-temperature superconducting materials and their application to electrical transmission lines may alleviate some of the constraints.

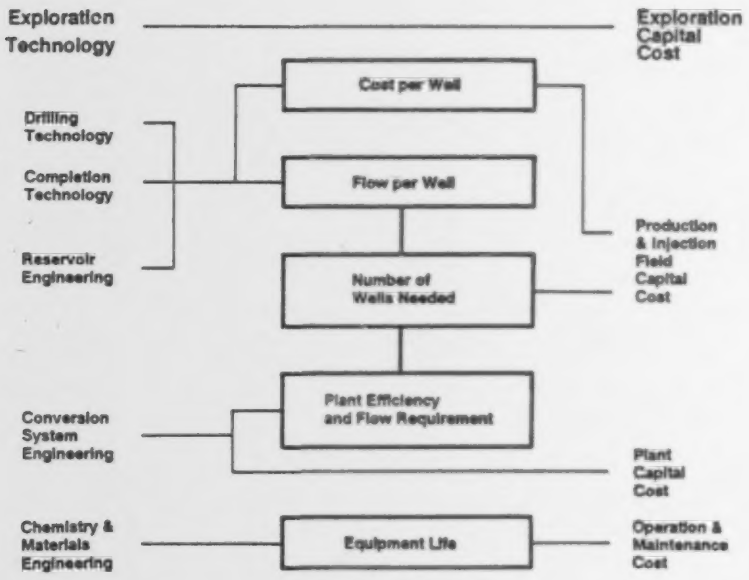

FIGURE 2-1 Geothermal Technology Cost Relationships.

Generation Alternatives To find a place in a utility's resource plan, geothermal operation must be more attractive than other generation alternatives. Because geothermal generation is considered baseload generation, the alternatives are usually nuclear power and coal. In view of the uncertainties now associated with nuclear projects, coal is the alternative most often considered.

Another recent approach to defining the competition is through the concept of "avoided" costs. If, by being less expensive, a geothermal plant can displace (or avoid) the energy and new capacity costs associated with other options in a utility's resource plan, it satisfies the avoided cost criteria.

Modularity and Size of Units Decisions and commitments to build geothermal projects are not as momentous as they are for large nuclear and fossil-fueled plants. Optimal development of most geothermal reservoirs requires the successive installation of small to medium-size power plants with a typical capacity of less than 100 MWe. Knowledge gained from the first small installations provides a basis for design in the commercial development of facilities.

Conversion Technologies

Power Generation

Three technologies are used for the conversion of geothermal heat into electricity (see Appendix C). In vapor-dominated geothermal fields, the wells produce slightly superheated steam that is routed to a condensing steam turbine, which in turn drives a generator. In liquid-dominated geothermal fields, a single or double flash system is necessary. The production wells flow spontaneously as the liquid boils, resulting in a two-phase mixture of brine and steam at the surface. The mixture is routed to a separator where the liquid and vapor phases are separated; the saturated steam fraction is then used to power a turbogenerator, and the separated brine is reinjected. Alternatively, a double flash system entails the flashing of the separated brine a second time to produce additional steam. For the third type, the binary cycle system, heat exchangers allow the hot brine to exchange its thermal energy with a working fluid having a low boiling point. This working fluid is vaporized, operating a turbine that in turn drives a generator. Binary cycles can be more efficient than flashed steam cycles for temperatures below 150° to 180°C. Thus, binary cycles are important to commercial development of the large moderate-temperature (< 150°C) U.S. geothermal resource.

Direct Heat Utilization

Because of the relatively low temperatures of geothermal fluids (typically 100° to 300°C), nonelectric direct uses are frequently

attractive for geothermal systems. These uses include industrial process heat applications, in which geothermal fluids might be used to generate steam or hot water to supply heat to a manufacturing operation. In the paper industry, for example, large amounts of steam are required for pulp digestion and paper drying at temperatures from 100°C to 150°C. Space-heating applications for geothermal heat are also possible when temperatures of 70° to 100°C are suitable. Examples in the United States are found at Klamath Falls, Oregon, and Boise, Idaho, and they are common in Iceland and the USSR. Even lower geothermal fluid temperatures (< 50°C) can be upgraded by heat pump design, as they are in Auburn, New York, and in France.

One economic advantage to process heat applications results from the inherently large load factors of many industrial processes. Space-heating applications are less attractive because of their lower load factors. Substantial use of geothermal energy for space heating in the United States would require extensive and costly retrofitting.

In some cases, cogeneration may be particularly well-suited to geothermal resources. Such cogeneration would include combined electric power and process heat supply systems for large industrial users and the use of geothermal heat for feedwater heating in a fossil-fueled base station power plant.

A substantial fraction of the U.S. annual energy budget of about 80 quads is consumed to produce heat used at temperatures below 20°C. Recent estimates indicate that over 25 percent or about 20 quads per year would be potential targets for geothermal energy supply. Clearly, the extent to which this energy source is used will depend in large part on the costs of geothermal heat relative to the competition, particularly natural gas and oil. Important factors for direct heat use include the distance between the geothermal resource and end user, which is critical to fluid distribution costs; the chemistry of the geothermal fluid, because it may lead to corrosion and scaling of heat exchange surfaces; and the quality of the resource in terms of temperature and depth.

Environmental Concerns

Geothermal power projects are environmentally preferable to other sources of electricity for several reasons. First, geothermal projects produce the resource and convert it to electricity at the same location, limiting adverse effects to one area. In contrast, the effects of coal-fired power plants include not only those at the plant but also those from mining, transportation via slurry pipeline or rail cars, stockpiling, and storage. In addition, since enactment of the 1978 Federal Power Plant and Industrial Fuel Use Act, coal has been the fuel predominantly used for power plants, and its combustion allegedly contributes to two pressing environmental problems: acid rain from sulfur dioxide emissions and "the greenhouse effect" from carbon dioxide emissions. Further, perceived nuclear risks have made construction of nuclear power plants increasingly unpopular.

Some environmental effects are common to different resources and localities, though their importance and severity vary from site to site. These potential effects include those on land use; air emissions; production of waste products from environmental control, some of which may be hazardous; water consumption and water quality; land subsidence; induced seismicity; and noise.

Building a geothermal or any other power plant causes land use and visual changes, but careful development has minimized them. As discussed later, hydrogen sulfide (H_2S) abatement procedures have successfully reduced air emissions to acceptable levels. However, these procedures result in solid wastes that must be disposed of. Prior to disposal, industry is considering the recovery of zinc, lead, silver, and other useful products.

Operating geothermal plants produces wastes because of the pollutants in geothermal fluids. A new federal Environmental Protection Agency study of geothermal drilling wastes could lead to a requirement for their off-site disposal if the study concludes that they meet any of the definitions of hazardous characteristics set forth in regulations pursuant to the Resource Conservation and Recovery Act (40 CFR Part 261). Such a requirement would have little effect on Imperial County, California, for example, where in order to protect agricultural interests, on-site disposal is not allowed.

With regard to geothermal plants' consumption of water, dry steam and flashed steam systems use their own condensed steam for cooling and inject excess fluids into the geothermal reservoir. This arrangement is a water-independent technology for dry steam plants, neither drawing from nor discharging into any publicly accessible waters. However, the use of flash steam plants may require make-up water under some operating conditions for part of the year. The use of binary systems for power production from moderate-temperature hydrothermal, hot dry rock, and geopressured systems requires an external source of cooling water. When cooling water is required for power plant operation, water could become a critical issue in areas with water shortages.

Land subsidence is also site-specific, depending on the characteristics of the geothermal reservoir and the amount of fluid produced. The problem can be alleviated or avoided altogether in one or more ways. One way is to stop withdrawal. Another is to repressure the reservoir by reinjecting of geothermal fluids or surface waters. In any event, the problem must first be identified and its possible deleterious effects evaluated. Industry is working closely with local government and agricultural interests to maximize the return of produced fluids into reservoirs and to monitor ground levels carefully so that prompt corrective action can be taken if necessary. So far, this has not been needed.

Injection of fluids into the ground can increase microseismic activity (earthquakes too small to be detected other than by sensitive instruments). These effects are highly site-specific. However, analysis of the energy involved in earthquakes suggests that injection is highly unlikely to trigger potentially damaging events. There are local requirements in certain earthquake-prone areas, such as the

Imperial Valley in California, that require monitoring microseismic activity to develop baseline studies and to distinguish between induced and natural seismic activity.

Noise pollution can be a problem, particularly during drilling and testing. Once a geothermal field is producing, however, noise levels are easily reduced to acceptable levels. During production, the geothermal fluids normally flow fairly silently through insulated pipes to the power plant. However, fluids may escape noisily from newly drilled wells or wells undergoing tests, pressurized hot water in liquid-dominated fields being discharged to the atmosphere and flashing in the process, and possibly large quantities of steam vented to the atmosphere when a power plant is shut down either inadvertently or for maintenance. All these noises are presently mitigated by means of mufflers that destroy the kinetic energy of the discharging fluids, reduce the volume of noise and deflect it skyward, and lower the pitch to a frequency level tolerable to people.

Generic Development Needs

Hydrothermal reservoirs with favorable characteristics are being exploited competitively, and the major short-term emphasis is on techniques that enable development of lower-quality reservoirs. As these technologies are developed, they can be extended to the other geothermal resources. Further development of techniques is needed to locate, delineate, characterize, and manage geothermal reservoirs. Drilling costs are high because of high temperatures, hard rocks, and corrosive fluids. The ability to reduce these costs will greatly enhance the economic competitiveness of geothermal energy development. Corrosive geothermal waters cause early failure of materials if corrosion prevention techniques and resistant materials are not used. Research and development (R&D) is needed on corrosion prevention techniques, high-temperature elastomer formulations for dynamic seals, cost-effective corrosion-resistant materials, elastomer-lined casings, and materials for heat exchanger tubing and well casings. Downhole pumping, which is often used for moderate-temperature resources, requires reliable motors and cables. Measuring, recording, and evaluating downhole conditions requires the development of reliable high-temperature downhole instrumentation. Successful exploitation of a reservoir requires technology for disposing of large quantities of spent brines. Often, the fluid must be disposed of by subsurface injection. To ensure efficient injection, R&D is required on siting injection wells and improving application of tracer methods for predicting and monitoring fluid migration. Developments required for conversion technologies include improved performance cycles and components (see Appendix D and later sections in this chapter).

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CURRENT STATUS OF THE DOE PROGRAM

Industry has conducted geothermal R&D since the 1950s. The federal government has been involved since a geothermal program was established by the Atomic Energy Commission (AEC) in 1971 (see Appendix E for a description of private and public R&D). In 1977, federal efforts were moved to the Department of Energy (DOE), with a formal commercialization program accounting for the largest part of the budget from 1977 to 1981 (see Table 2-1). This formal commercialization program was initiated in 1977 to promote early use of hydrothermal resources for both power generation and direct use. A policy decision in 1981 shifted emphasis from commercialization back to R&D, where it remains today.

As can be seen from Table 2-1, DOE's budget for geothermal energy development declined significantly from $158 million in 1979 to about $21 million in 1987. The current low prices of petroleum have decreased the urgency of pursuing R&D in alternative energy technologies. DOE's budget has been cut for R&D in alternative technologies, affecting development of the four geothermal resource types and their potential contribution to U.S. energy supply.

At the direction of Congress, DOE's long-term responsibility for geothermal energy R&D is to determine and improve the scientific, engineering, and economic feasibility of using energy from all types of geothermal systems. This R&D is to provide options to be developed by the private sector in response to market forces.

The development of technology for hydrothermal energy, the most attractive for technical and economic reasons, receives near-term emphasis by both government and industry. Hydrothermal reservoirs with the most favorable characteristics are being exploited competitively. Thus, the major short-term focus is on improving the feasibility and economics of hydrothermal development of reservoirs of lower quality. In the long term, these technologies can be used to locate more hydrothermal resources and develop geopressured, hot dry rock (HDR), and magma energy resources.

R&D funds for HDR and magma energy extraction are included under the umbrella of geothermal technology development, but they are listed separately in Table 2-1. The HDR program was launched in 1973 with one-third the total AEC geothermal energy budget, and in 1974 this program element received more than half the $7 million appropriated for geothermal R&D. The geopressured geothermal energy program began in 1974. Magma energy extraction R&D was not undertaken until 1984, after seven years of scientific study funded by DOE's Office of Basic Energy Sciences, which was designed to test its technical feasibility.

HYDROTHERMAL RESOURCES

Resource Description

Hydrothermal energy includes water and steam trapped in fractured or porous rocks. Hydrothermal systems are liquid-dominated or

TABLE 2-1 Budget History of the DOE Geothermal Technology Program (in millions of dollars)

Year	Hydrothermal Industrialization	Geothermal Technical Development	Geopressured Resource Development	Hot Dry Rock Resource Development	Magma Resource Development	Other	Total
FY 1976	13.3	10.5	0.3	4.0	-	3.2	31.3
TQ[a]	5.0	3.1	0.8	1.6	-	1.3	11.8
FY 1977	23.7	11.8	6.6	6.0	-	4.9	53.0
FY 1978	54.5	29.2	16.5	6.0	-	1.7	107.9
FY 1979	70.9	42.6	27.7	15.0[b]	-	1.8	158.0
FY 1980	70.4	26.0	36.0	15.0[b]	-	1.8	149.2
FY 1981	55.4	33.9	31.9	14.0[b]	-	2.3	137.5
FY 1982	31.2	10.4	16.7	10.0[b]	-	1.6	69.9
FY 1983	33.0	6.9	8.4	7.5[b]	-	1.3	57.1
FY 1984	2.0	14.3	5.0	7.3[b]	0.8	1.1	30.5
FY 1985	1.0	13.3	5.4	9.4[b]	1.3	1.7	32.1
FY 1986	1.9	10.1	4.4	7.1[c]	1.7	1.2	26.4
FY 1987	2.0	5.6	4.0	8.0	0.5	0.8	20.9
Total	364.3	217.7	163.7	110.9	4.3	24.7	885.6

[a]Three-month period when the federal government changed the fiscal year beginning from July 1 to October 1.
[b]An additional $5 million was provided by the Federal Republic of Germany (50 percent) and Japan (50 percent).
[c]An additional $2.5 million was provided by Japan.

SOURCE: DOE (1987).

vapor-dominated (steam), based on the dominant phase in the fractures and large pores. Wells used to recover this type of energy are usually a few hundred to as much as 4,000 m (14,000 ft) deep. The temperatures for power production range from 150° to 360°C (300° to 680°F), with most useful temperatures at the upper end of the range. The highest-quality U.S. hydrothermal resources are in the western states, where relatively young volcanoes or a thinning of the earth's crust are associated with many shallow high-temperature systems. A large number of low-temperature systems (< 90°C [194°F]) are also found in the west, with more scattered occurrences in the eastern and central states (Reed, 1983).

Power generation with the dry steam from vapor-dominated reservoirs has been commercial for a number of years. Very hot water systems (> 180°C [350°F]) have recently been developed for power production in the United States. In addition, moderate-temperature systems are being successfully used for operating small binary cycle conversion units and in many nonelectric applications where the heat of the fluids is used directly. Technology for using hot water in the moderate temperature range, from 90° to 150°C (194° to 300°F), for power plants is still in the development phase.

Resource Base

In the foreseeable future, the resource base of hydrothermal systems is limited to that part of the resource shallow enough to be reached by production drilling to a depth of about 3 km (10,000 ft). Assessments of the U.S. resource base by category are as follows (Muffler, 1979; White and Williams, 1975):

- o High-temperature (> 150°C) vapor-dominated systems: 300 quads (49 billion bbl petroleum equivalent)
- o High-temperature (> 150°C) hot-water systems: 4,500 quads (742 billion bbls petroleum equivalent)
- o Intermediate-temperature (90° to 150°C) water systems: 4,900 quads (809 billion bbl petroleum equivalent)
- o Low-temperature (< 90°C) water systems: 34,000 quads (5,600 billion bbl petroleum equivalent).

Together these resources represent nearly 44,000 quads of energy, the equivalent of 7,200 billion bbl of petroleum or approximately 720 Prudhoe Bay petroleum fields. These estimates of the resource base are speculative, but in comparison to the annual U.S. petroleum production of about 4 billion bbl, recovery as low as 1 percent would still represent a gigantic energy resource.

Current Status of Development

Worldwide power generation with geothermal energy from hydrothermal resources is in its eighty-fourth year. The first experiment was

conducted at Larderello, Italy, in 1904, when five light bulbs were lighted with the electricity produced from a small dynamo driven by geothermal steam. From this early beginning, the geothermal power generation capacity at the Larderello steam field, one of the few dry steam fields identified worldwide, has grown to about 500 MWe. A total of 900 MWe is projected for 1995.

The largest geothermal field in the world is The Geysers, a vapor-dominated (steam) field in Sonoma County, California, 75 miles north of San Francisco. Developments began in 1960 with a 12 MWe power-generating facility that has grown to 1,800 MWe. Total development capacity is estimated at more than 2,000 MWe. This electricity produced from The Geysers field will displace 800 million bbl of petroleum needed to generate the same amount of electrical energy over the life of all the power plants at this generating facility.

Liquid-dominated hydrothermal power generation outside the United States began in New Zealand in 1959 with an 11-MWe unit. Today, units totaling a 167-MWe capacity are operating at two sites, and additions totaling nearly 120 MWe are planned.

Mexico, the Philippines, and Indonesia all began aggressive geothermal programs in the 1970s, and geothermal power currently accounts for a substantial percentage of the total power generated in these countries. Geothermal power production not only provides developing countries an indigenous resource but also permits those with exportable energy resources to sell them abroad and generate foreign currency (Kestin, 1980).

In the United States, the use of liquid-dominated hydrothermal geothermal resources was initiated in the Imperial Valley, California, in 1979 with the operation of a 12.5-MWe binary power plant. Subsequently, a 10-MWe flash power plant in 1980 and the world's largest binary power plant of 45 MWe in 1985 were put into operation. From mid-1979 to mid-1986, worldwide geothermal capacity grew 269 percent, for an annual growth rate of 15 percent (DiPippo, 1986).

In addition to generating electric power, hydrothermal geothermal energy is used in many nonelectric applications worldwide. For example, geothermal steam provides process heat for pulp and paper production in New Zealand. In Iceland and in Oregon and Idaho, water-dominated resources are used for space heating (see Appendix F for an inventory of geothermal plants).

Economic Issues and Projected Costs

The cost comparisons in hydrothermal power development are illustrated in Figure 2-1. In this context, the most important objectives are reducing fluid production costs and fluid flow requirements per unit of energy output. The same objectives hold for other geothermal resources. In the current energy market, the cost of generating new capacity at The Geysers make thermal power one of the lowest-cost generation options. It is competitive with new gas turbines and would be cheaper than a conventional petroleum-, coal-, or nuclear-fueled

plant. Hot water geothermal development is more complex than at The Geysers and therefore is more costly, but as shown in Figure 2-2, electricity from this source should be cheaper than from a newly installed coal- or nuclear-fueled plant.

If fossil fuel prices return to 1985 levels, the cost advantages of gas turbines and gas- or oil-fired steam electric plants diminish and electricity from geothermal resources, whether steam or hot water, becomes more attractive than the other options. This point is illustrated in Figure 2-3.

Environmental Concerns

Among other considerations, land use is a part of hydrothermal resources development. Most projects in operation are in rural or undeveloped areas. In the Imperial Valley of California, the projects were designed to minimize the amount of land removed from agriculture. Drilling pads are located at corners of fields and pipelines routed along farm roads. For the quiet resort areas near The Geysers steam field, strong consideration was given to the visual effects of each plant and pipeline, particularly those that could be placed atop the mountain ridges. Though only 5 to 10 percent of the total project area was used for well pads, power plants, roads, and pipelines, this undeveloped area definitely changed character.

Other environmental factors require special consideration in developing hydrothermal resources, typifying some of the "worst case" situations in geothermal development. Major environmental concerns that earlier impeded geothermal development include the odor of hydrogen sulfide at The Geysers and the high salinity of the fluids in the Salton Sea and Brawley reservoirs in Imperial Valley. In addition, solutions to these "worst cases" produce ancillary waste streams that now represent the most costly environmental requirement confronting the industry--land disposal of wastes deemed hazardous under federal and state regulations.

Methods used to control the H_2S emissions at The Geysers are now in full compliance with stringent California requirements. However, nearly all these methods produce sludges containing trace levels of arsenic, mercury, vanadium, and other metals. If concentrations of these elements exceed the maximum values set forth in Title 22 of the California Administration Code, they must be disposed of at a state-approved hazardous waste disposal site.

In the Imperial County of southern California, geothermal power production with the hypersaline fluids at the Salton Sea and Brawley reservoirs is possible only with a technology that creates a sludge containing primarily silica. This process removes the solids from the brine ahead of the turbine and again before injection. A 34-MWe dual flash plant in the area produces about 50 tons of sludge for disposal every 24 hours. Because of the large volume of these wastes, the county planning officials, while welcoming the benefits of geothermal development, are concerned about the continued availability of disposal facilities.

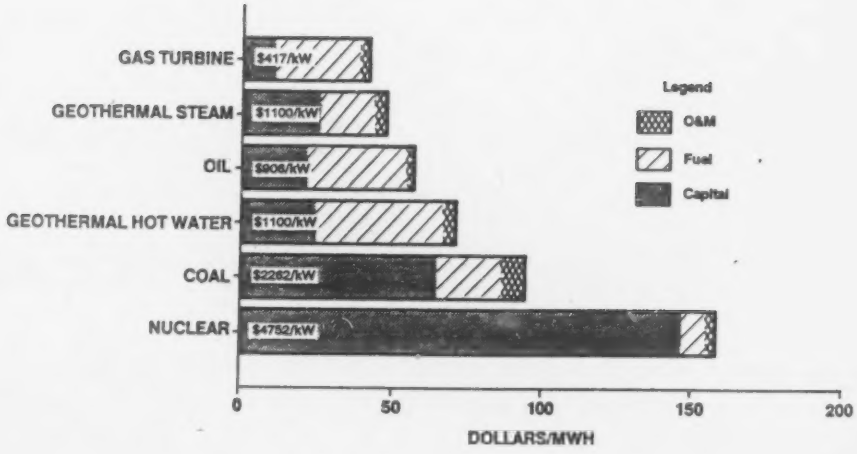

FIGURE 2-2 Estimates of Electricity Costs with Oil at $18.50 per Barrel.

SOURCE: Based on data from the California Energy Commission (1985).

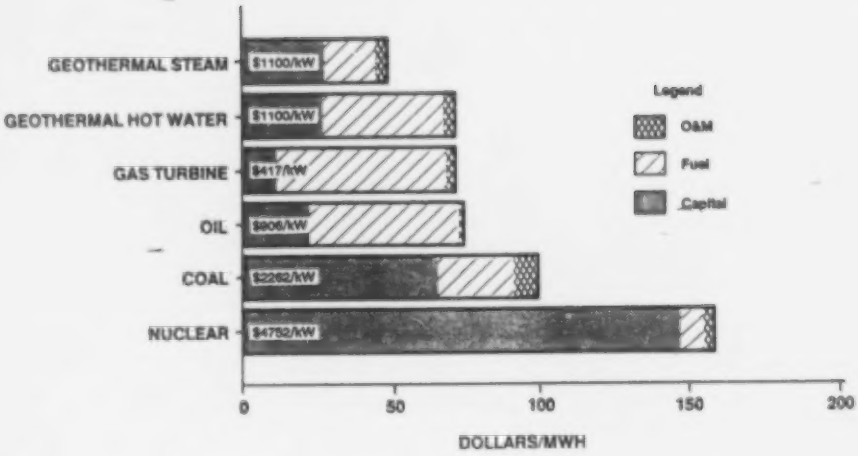

FIGURE 2-3 Estimates of Electricity Costs with Oil at $28 per Barrel.

SOURCE: Based on data from the California Energy Commission (1985).

The chemical nature of the resource and its environmental effects limit its development. The Forest Service and, to a less extent, the Bureau of Land Management, have determined that geothermal operations are not compatible with other authorized land uses in areas considered environmentally sensitive. For example, the Forest Service denied geothermal leasing in the Mt. Lassen, California, Known Geothermal Resource Area (KGRA), as it has done in promising areas in Oregon and other less prominent areas. Congress also foreclosed any leasing in the Island Park KGRA adjacent to Yellowstone National Park.

More recently (October 18, 1986), Congress placed additional restraints on federal land use, with a rider to the Continuing Appropriations Resolution for Fiscal Year 1987 (P.L. 99.5000). Leases issued must now include stipulations to protect the thermal features, including the right of the government to suspend the activities of leaseholders, temporarily or permanently, if they are determined to exert an adverse effect. In consenting to a lease on forest lands, the Secretary of Agriculture must also consider the effects of activities authorized by the lease.

Another environmental consideration is land subsidence. At The Geysers, condensed steam is injected to maintain reservoir pressures and minimize subsidence. Injection should not affect the quality of local water resources if care is taken in design, construction, and maintenance. Groundwater aquifers are protected by specially designed well casings cemented in place in each well. Roads, well pads, drilling sumps, and power plant sites can be designed to minimize erosion and to control spill drainage into special catchment basins for proper disposal. All produced fluids not consumed in the power cycle should be reinjected into the producing reservoir. These operations can be monitored regularly to minimize accidental spills that might reach a watercourse.

Feasibility and Impediments to Growth

The issues of feasibility and impediments to growth, discussed briefly under "Generic Development Needs," are detailed in Appendix D. Again, these technologies must be developed for all types of geothermal resources. Specific R&D recommendations are made in the section below. Institutional factors, such as permitting requirements, leasing laws, regulations, and tax treatment can always be improved upon. Currently, they present no insurmountable barriers for geothermal development except in a few specific cases. Federal and state governments need to streamline the approval process in order to minimize incurred costs.

Research and Development Program

To determine the research needs and priorities of the geothermal industry, DOE obtains information from many sources; the latest was consolidated in DOE's 1986 research plan. It was reviewed at a meeting

at the Los Alamos National Laboratory on October 15 and 16, 1986, by 20 people from the U.S. geothermal community (see Appendix G). The Hydrothermal Technology Program described here is the program presented by this review panel to the DOE Assistant Secretary for Conservation and Renewable Energy. The longer-term resources of geopressured, hot dry rock, and magma energy are discussed elsewhere. The Los Alamos review panel concluded that technology is the major barrier to growth of the geothermal industry and that improvement and developments are necessary in the areas listed below.

Reservoir Technology

The objective of research in reservoir technology is improvement in delineating, characterizing, and managing hydrothermal reservoirs to predict their long-term behavior and to design optimal production and injection strategies. Utilities and financial institutions are reluctant to commit funds and other resources to a geothermal project if long-term production is not ensured. Work in this area can be classified as follows:

- o Reservoir definition--Improvement of surface and borehole geophysical, geological, and geochemical methods for:
  1. Reservoir location and delineation
  2. Hydrological modeling
  3. Fracture detection
- o Reservoir performance--Improvement of predictions of reservoir performance over 30-year lifetimes requiring development in:
  1. Well testing
  2. Performance matching
  3. Reservoir modeling
  4. Reserve forecasting
  5. Geophysical and geochemical monitoring
- o Field management--Improvement of energy extraction and reservoir operations. Additional work is required on:
  1. Well spacing
  2. Injection
  3. Computer modeling
  4. Well completion and operation
  5. Scaling and corrosion
- o Field cast studies--Testing and transfer of technology through cooperative studies of currently operated fields in the United States and abroad on all types of hydrothermal systems:
  1. Low- and moderate-temperature systems
  2. High-temperature systems
     - hot water (fracture and matrix-controlled systems)
     - vapor-dominated systems

Drilling Technology

Reducing drilling costs can most improve the economics of geothermal projects. The objective of proposed research is to reduce costs 5 percent per year for 10 years, thus cutting drilling development costs one half. Development to improve drilling technology is required in the following areas:

- Hard rock penetration:
  1. Drilling bits, reamers, etc.
  2. Coring bits
  3. Downhole motors and turbines
- Formation testing and well completions:
  1. Open-hole packers
  2. Reservoir stimulation
  3. High-temperature cements and cementing techniques
- Drilling fluids and lost circulation control including lower cost, high-temperature fluids.

High-Temperature Instrumentation

A subcategory of drilling technology is the information gathering devices used in wells during drilling or after completion. In this area, improvement is needed in an array of instruments:

- Fracture detection and mapping
  1. Acoustic televiewer
  2. Downhole radar and electromagnetic tools
  3. Downhole seismic instruments (for vertical seismic profiling, geophones)
- Electric cables
  1. Armored multiconductor
  2. Fiber optics
- Fluid samplers
- Logging tools
  1. Geophysical monitors
  2. Pressure monitors

Conclusions and R&D Budget Recommendations

Based on the above discussion of hydrothermal energy resources, the committee reached the following conclusions about hydrothermal resources:

- Estimates of the hydrothermal resource base are speculative but so large that a small recovery factor represents a large addition to U.S. energy supply.

- Some hydrothermal resources are now economically competitive. Technology development and higher fossil fuel prices will make other hydrothermal resources economic.
- For hypersaline solutions, the most costly environmental problem confronting the industry is land disposal of solid wastes, some of which are deemed hazardous.
- Institutional factors are not insurmountable barriers to geothermal development, except in a few special cases, but they need to be streamlined to reduce costs.

Based on the R&D needs listed above, the committee recommends funding for DOE hydrothermal development slightly less than $17 million per year for three years (1988 to 1990) followed by $14 million per year for 1991 and 1992 (see Table 2-2). For a successful program, significant and stable funding over a number of years should be committed. Such funding is required for an orderly and systematic research program and for attracting the most qualified people to R&D activities. With this type of commitment, the committee estimates that cost-sharing funds may be obtained from industry at about $3.5 million per year for drilling technology and high-temperature instrumentation. The committee also believes that with further research successes, the funding could be reduced somewhat later in the five-year period.

GEOPRESSURED GEOTHERMAL RESOURCES

Resource Description

Geopressured geothermal energy is unique, consisting of three forms of energy: water at temperatures of 150° to 230°C (230° to 450°F) at typical depths of 15,000 ft or more, natural gas (methane) dissolved in the water at solution gas levels averaging 25 to 40 standard cubic feet (scf)/bbl of water, and hydraulic energy in the form of pressure. The pressure gradients approach 1 psi/ft, almost twice the normal pressure gradient, and allow the water and contained natural gas to flow to the surface at extremely high pressures.

The principal U.S. location of these resources is beneath known oil and gas deposits in the Gulf coast of Texas and Louisiana, but geopressured geothermal resources have also been found in six other basins in the country, including the Central Valley of California. At least 60 similar basins are known in other countries, and probably many others are yet to be discovered in the United States and elsewhere by deep drilling beneath established petroleum-producing provinces.

Resource Base

Resource assessments for both methane and thermal energy from water have been published by the U.S. Geological Survey (USGS, 1979). Assessment was limited to the onshore portion of the U.S. Gulf coast and to a depth of 6.86 km (22,500 ft) from the surface. Resources contained in the

TABLE 2-2 Committee Budget Recommendations for Hydrothermal Development in the DOE Geothermal Technology Program (in millions of dollars)

	Fiscal Year				
Element	1988	1989	1990	1991	1992
Reservoir technology[a]	7.0	7.0	7.0	6.0	6.0
Drilling research	4.0	4.0	4.0	3.0	3.0
High-temperature instrumentation	1.5	1.5	1.0	1.0	1.0
Conversion technology	3.0	3.0	3.0	3.0	3.0
Cross-cutting research	1.2	1.2	1.2	1.2	1.2
Total	16.7	16.7	16.7	14.2	14.2

[a]Industry cost-shared funding estimated by the committee at $3.5 million per year.

sandstones are estimated at 5,800 quads of thermal energy and 3,220 quads of natural gas. No estimate was made of hydraulic energy recoverable from the high wellhead pressures.

Although current field tests indicate larger than expected recoveries from geopressured geothermal resources, the USGS conservatively estimates only a 3-percent recovery from the onshore portion of the Gulf coast basin, or 164 quads of thermal energy and 102 quads of natural gas. This estimate thus totals 266 quads of recoverable energy for one third of the basin, an addition of 137 percent to currently known natural gas reserves in the coterminous United States. Given the conservative nature of this estimate, it is apparent that the geopressured resource may represent a large addition to the U.S. energy base, depending, however, on its economics compared to other energy sources.

Current Status of Development

The geopressured geothermal program is still in development. Research and field testing began in 1974, under the auspices of DOE and its predecessor agencies, to provide the scientific and technological base for determining technical feasibility. Once the resource base was established and research in geology and engineering had developed methods for field testing, DOE initiated the following steps: (1) selection of "wells of opportunity," that is, wells drilled by industry in search of petroleum or natural gas without success, to be taken over and flow tested for short periods to examine flow rates, natural gas content, and pressures; (2) drilling of new wells at geologically optimal locales to assess long-term reservoir performance; and (3) studies of environmental effects while production of design wells was monitored.

The "wells of opportunity" program began in 1978. Nine wells were tested for one week each. These tests confirmed the researchers' belief that natural gas was present everywhere at saturation levels or higher. In fact, one well produced natural gas during testing and was returned to the operator for commercial production. The test also appeared to validate high flow rates and pressures but could furnish no information on long-term reservoir performance.

Four new wells drilled in Texas and Louisiana between 1979 and 1982 were instrumented for long-term performance tests. Testing of two is complete; the other two are still undergoing flow tests. One, the No. 2 Pleasant Bayou well in Texas, will be the site of an electrical demonstration facility under the sponsorship of the Electric Power Research Institute (EPRI). This hybrid facility will include a gas-fired turbine, a binary cycle thermal power system, and a pressure reduction turbine to generate electricity from all three forms of energy present at the wellhead.

Industry pioneered the binary cycle thermal system in geothermal fields in the Imperial Valley of California, but the system combining all three energy sources has not been attempted before.

The No. 1 Gladys McCall well in Louisiana has produced almost 23 million bbl of hot water to date, and more than 1 million cubic feet (MMcf) of natural gas per day is sold. This is the first well of its type to produce in excess of 30,000 bbl of water per day and, at the same time, to have natural gas sold in quantities formerly associated only with commercial gas wells. Mobil Oil Company has offered DOE another well in Louisiana for testing. This well appears to have optimally geopressured sandstones, with some possibly containing free gas in excess of solution gas levels of 25 to 40 scf/bbl. However, current budgetary constraints will permit testing only one well in the fiscal year 1987 to 1988.

Economic Issues and Projected Costs

Although geopressured geothermal resources are not economically attractive under current energy market conditions, they need further investigation. It is estimated that geopressured gas can be produced without electrical power usage for approximately $5 per thousand cubic feet (Mcf), but the EPRI power demonstration facility will provide a better test of use and costs. Binary cycle systems capable of extracting heat from water at 167°C (300°F) are in commercial service in the western states. The additional boost from hydraulic energy and natural gas power generation possible only with this resource may further improve the economics and interest industry, once long-term evaluations of reservoir performance and equipment provide more information on the energy that can be produced.

Environmental Concerns

Environmental studies on geopressured geothermal energy use began in 1975 at both the University of Texas and Louisiana State University. They indicated that the principal environmental effects to be monitored are reinjection and disposal of water and potential subsidence from withdrawing large volumes of water. As a result, injection wells were drilled alongside the new wells and plans made to reinject spent waters into shallow (1.22 km deep) saline aquifers beneath all freshwater zones in accordance with state commission regulations. To date, the reinjection program has proceeded with spectacular success. More than 22 million bbl of water have been reinjected at the Louisiana well site at very low surface pressures (300 psi) without difficulty. This is probably the largest quantity of water ever injected in one well in the Gulf coast.

Subsidence is more difficult to address, because it may be a long-term effect. Newly drilled wells were instrumented at the time of completion with radioactive tracer bullets to check for compaction of sediments later. Sites at locales will be surveyed for changes in ground elevations. So far, there is no evidence of subsidence. However, monitoring is necessary at both sites as fluid withdrawal continues, particularly in south Louisiana, where natural subsidence (at about 2 mm per year) is lowering elevations and causing loss of land.

Feasibility and Impediments to Growth

Aside from current economics, the principal requirements for increased industrial interest in geopressured geothermal resources relate to long-term performance, verification of reservoir models, other technology new and unique to this energy source, and confidence in a lack of environmental constraints. Research has achieved many breakthroughs, and early problems no longer of concern include improved logging interpretation, prevention of scaling in wells, and reinjection. Of continuing concern is reservoir behavior. Recent well tests indicate that pressures higher than predicted are being sustained, but the causes are questionable. Under investigation are dewatering of adjacent shales and high bulk compressibility of sediments. The mechanisms controlling fluid flow in these reservoirs are clearly different from those of conventional hydrocarbon reservoirs, and models developed by industry require modification. Long-term testing is required to determine continued productivity and well spacing. Similarly, the environmental issue of subsidence will require monitoring in both wells and at the surface of each well site for several years to verify the satisfactory results to date.

Conclusions and R&D Budget Recommendations

Based on the preceding discussion, the following conclusions were reached:

- o Geopressured geothermal resources may represent a large addition to the future U.S. energy supply.
- o The principal environmental issues for use of this resource are reinjection and disposal of water and potential subsidence from withdrawal of large volumes of water.

The current $4 million DOE budget for development of geopressured geothermal resources is sufficient to continue to test one design well, put in place the EPRI electric power demonstration experiment, and at the same time monitor subsidence at one site. As a result, DOE is considering shutting out the Louisiana well, which has the longest production history, the longest injection history, and the most potential for studies of environmental effects. It seems prudent to continue testing this well for two reasons: (1) the large initial costs of well drilling and completion have been met and (2) the data are needed to establish the long-term value of the resource and to induce industrial interest.

Because additional free gas may be obtained in many geopressured aquifers, a matter still under investigation, the Louisiana well offered to DOE by Mobil Oil Company could be useful in evaluating this concept. All researchers deem the well important to the program and, as stated above, the expensive well drilling and completion have been done by the oil company. The committee estimates that an additional $3 million per year is required for testing the current wells, placing the new well in

production, gathering data and modeling, monitoring for subsidence, and other research attendant to the project. Therefore, a sustained budget of $7 million per year for five years is required to resolve these important technological issues for geopressured geothermal energy use. At that point, it is anticipated that the DOE program might be phased out.

HOT DRY ROCK GEOTHERMAL RESOURCES

Resource Description

Unlike hydrothermal or geopressured resources that require both hot rock and indigenous fluids, hot dry rock resources consist of hot rock alone at accessible depths in the earth's crust. The U.S. program has focused on engineering systems in impermeable granitic formations. The primary stimulation technique uses hydraulic fluid pressure to open and propagate fractures from a directionally drilled well, resulting in a fracture network of high effective permeability. This stimulated region is then connected to a second well to complete the underground system. Heat is extracted by circulating water from the surface, down one well, through the fractured rock network, and up the second well. The heated water than passes through a specially designed power plant on the surface, where electricity or process steam is generated.

The major technical challenges for HDR systems center on engineering the underground fracture network to maximize its heat extraction capacity while minimizing pressure and fluid losses. A large open-fracture labyrinth must be created to allow fluid to sweep efficiently through a significant volume of hot rock. Because heat transport in these systems is inherently limited by the low thermal conductivity of the rock matrix, required rock-fluid heat transfer surface areas and volumes are large.

Heat extraction from HDR reservoirs, like other geothermal systems, could be provided continuously, making them well-suited for baseload electric and nonelectric (process heat) applications.

Resource Base

A major incentive for HDR development is the estimated large magnitudes and widespread distribution of the HDR resource throughout the nation. The HDR resource base ranges from low-grade regions with normal to near-normal thermal gradients of 20° to 40°C/km, to high-grade regions with gradients above 40°C/km. The lower-grade resource is distributed more or less uniformly throughout the United States; the higher-grade resource is found mostly in the west, frequently within or near active hydrothermal systems. However, it is not clear how much of this geothermal resource base qualifies as "dry rock." Several preliminary estimates of the U.S. HDR resource base have been developed in the past 15 years. They were provided by the USGS (Smith and Shaw, 1979; White and Williams, 1975), the Los Alamos National Laboratory

(LANL) (HDRAP, 1977; Rowley, 1982), and others (Armstead and Tester, 1987). Although the actual numerical values of these preliminary estimates differ, the methods used are similar.

Recent estimates of the higher-grade geothermal resource base suggest that more than 2 percent, or about 1.8×10^5 km^2 (6.9×10^4 square miles), of U.S. land area should have average gradients in excess of 45°C/km (Kron and Heiken, 1980). This estimate would amount to some 650,000 quads, which is the energy equivalent of 116 trillion bbl of petroleum or 11,600 Prudhoe Bay fields. The lower-grade resource is 10 to 15 times as large, although what fraction of it would qualify as HDR has not been established.

Based on all estimates, the amount of potentially usable geothermal energy is immense, orders of magnitude larger than the total of all estimated fossil resources. The critical question is how much of this vast geothermal resource base can be recovered within technical and economic constraints. As a point of comparison, usually less than half of the petroleum in an underground reservoir is actually produced. At this stage of HDR resource development, how much of the estimated resource base truly fulfills the criteria for HDR and what fraction is economically recoverable are not known. However, even if only between 0.1 and 0.01 percent of the accessible HDR resource base proves economically extractable, the impact on the U.S. energy supply would be far-reaching. For economic reasons, high-grade HDR resources are likely to be developed first because they require much shallower drilling and significantly lower reservoir development costs.

Thus, given favorable outcomes of further developments, HDR resources could provide a long-term energy supply. HDR could thus be treated as an advanced energy concept not limited by the size of the available resource, similar to controlled thermonuclear fusion or solar photovoltaics. For this reason, HDR development should not be regarded as being in competition with the near-term development of hydrothermal or geopressured geothermal resources.

Current Status of Development

Through 1986, only two major field programs in the world were aimed at developing HDR technology: the U.S. site at Fenton Hill, New Mexico, and the Rosemanowes site in Cornwall, southwest England. The U.S. program has been managed for DOE by LANL since its beginnings in the early 1970s. In 1979, the U.K. program began in the field managed by the Camborne School of Mines primarily under U.K. and DOE sponsorship (Batchelor, 1984).

In 1979, an International Energy Agency (IEA) agreement was adopted to provide for non-U.S. participation in the HDR program at Fenton Hill. Under the IEA agreement, Kernforschungsanlage-Julich GmbH (representing the Federal Republic of Germany) and the New Energy Development Organization (representing Japan) participated in the project from 1980 to 1986, providing $32.5 million in supporting funds and a number of technical staff assigned to work at LANL. Through fiscal year 1986, U.S. funding support for the project totaled $105.5

million, most of it used for field testing at Fenton Hill. Progress at Fenton Hill has been documented in considerable detail by the LANL team (Dash et al., 1983; Smith et al., 1975; Whetten et al., 1986).

The world's first operating HDR reservoir, with rock temperatures of 185°C, was completed at Fenton Hill in 1977 (at 2,740 m [9,000 ft] depth). The results of the first phase of testing were positive, clearly demonstrating that heat can be extracted at reasonable rates from a hydraulically stimulated region of low-permeability hot crystalline rock without serious technical and environmental problems.

To extend HDR technology to the higher temperatures and heat production rates required to support a commercial electric generating plant, drilling and stimulation of a larger and hotter HDR reservoir were initiated at Fenton Hill in late 1979. This second phase system was designed to have two directionally drilled inclined holes, with a vertical separation of approximately 300 m, at a 35° angle of inclination in the stimulated region. Early attempts to connect the wells using hydraulic fracturing were unsuccessful despite the substantial volume of water injected during massive fracturing operations in 1982 and 1983. Microseismic event maps suggest that the stimulated region consisted of a three-dimensional multiple-jointed network rather than a single fracture. With no hydraulic connection with the upper well, the LANL team decided to sidetrack from it to intersect the seismically active region. This procedure was successful, and in March and April of 1986, the new second phase reservoir was prepared for hydraulic circulation and heat extraction testing. Preliminary testing indicated adequate fluid production temperatures and acceptable water loss rates and flow impedances.

Current plans are to continue testing the redrilled second phase system at Fenton Hill with a long-term (about one year) circulation test. Scheduled for 1987 and 1988, it will characterize steady-state water losses and potential thermal drawdown by monitoring outlet temperatures and using chemically reactive tracers.

The main technical task remaining is enlargement of the two-well HDR reservoir concept to commercial sizes and production rates. Although this task is by no means small, as the field efforts at Fenton Hill and Rosemanowes have demonstrated, it does not require the great technical developments that are frequently necessary before some new energy technologies (such as thermonuclear fusion) can become a commercial reality.

Another useful feature of the heat mining concept is that it can be extended. If success can be achieved with a single pair of wells and an interconnecting network of fractures, then this limited system can be treated as a modular unit to scale up to extract heat from much larger volumes of hot rock. In fact, the first phase reservoir at Fenton Hill served as a module in designing the second phase multiple-fracture system. If reservoir stimulation from an inclined set of wellbores can be achieved as systematically as envisioned, then the technical hurdle of creating and testing a commercial-size system is certainly within reach during the next five years.

Economic Issues and Projected Costs

Estimates of the economics of HDR resources are not based on long-term information on reservoir performance. Similarly, data on well costs and power plant economics are projections based on certain assumptions. Drilling and completion costs are the most important cost component. Power plant capital costs are comparable to those for binary cycle or multistage flash plants designed for low-salinity, liquid-dominated hydrothermal brines ranging in temperatures from 200° to 300°C. Costs for aboveground equipment and piping for direct heat uses are also comparable to those for hydrothermal systems. Two primary factors control the cost of producing electricity or heat from HDR. The first is the grade of the resource, represented by the effective geothermal gradient. It strongly influences drilling costs. The second is the productivity of the reservoir, which is defined by several reservoir engineering characteristics, including initial fluid temperature, flow impedance, mass flow rates per pair of wells, and the thermal drawdown rate. The initial fluid temperature for a given HDR resource can be selected by drilling to a certain depth with a defined gradient. This fixes the individual well cost. The effective cost per unit of reservoir size is a function of the drawdown rate, which in turn is controlled by how much rock surface area and volume are contacted by the recirculated fluid.

As expected, economic forecasts for HDR show a strong dependence of breakeven electricity prices on drilling costs, assumed reservoir performance, debt interest rates, and anticipated rates of return on equity capital. Based on conditions corresponding to a high-grade HDR resource, such as at the Fenton Hill site, a break-even price of about 50 to 60 mills per kWh (5 to 6 cents per kWh) of electricity generated (in 1986 dollars) is predicted. These estimated prices depend strongly on several important performance and economic assumptions, which for this base case include: (1) a 40° to 60°C/km resource gradient; (2) a reservoir productivity of 75 kg/s per pair of wells, with about 20-percent thermal drawdown in 10 years; (3) drilling costs two to three times those of petroleum and gas wells of comparable depth (based on data from Fenton Hill and Rosemanowes); and (4) real interest and equity rates of 9 and 12 percent, respectively (Armstead and Tester, 1987).

An industrial group headed by Bechtel began an independent study of HDR economics for proposed development at Roosevelt Hot Springs, California, in late 1986. In addition, EPRI is providing updated forecasts. Preliminary predictions from EPRI and from a U.K. study (Shock, 1986) show HDR-produced heat and electricity to be competitive with oil priced at about $14/bbl for heat and $24/bbl for electricity. This estimate corresponds to an estimated price (in 1986 U.S. dollars) of $2.50 per million Btu for delivered heat, or about 61 mills per kWh (6.1 cents per kWh) for electricity. It is important to recognize that these estimates are merely forecasts and are site specific; they are based on the best available data on drilling costs, plant capital costs, and projected levels of reservoir performance. As yet, there are no operating geothermal power plants deriving their heat supply from HDR, and the economics of other HDR resources cannot be projected with certainty.

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Environmental Concerns

HDR resource development shares characteristics with other geothermal resource types that affect the environment. However, using the *presently envisioned concepts, mining heat from HDR reservoirs will* involve the recirculation of water in closed loops. Thus, effluents at an HDR plant site from the periodic purges that may be required will be few. Water loss to the rock formation is a concern, directly as a practical issue of consumption in arid regions and indirectly if it induces seismicity. The magnitude of seismic risk depends strongly on the geological setting of the HDR system and on how heat is mined from the reservoir. Field evaluations so far lead to an optimistic outlook. Water loss rates have been controlled using downhill pumping and other reservoir pressure management strategies. Further, the lack of induced seismic hazards under long-term pressurized circulation in several fractured HDR reservoirs in the United States and the United Kingdom is encouraging. In any development situation, seismic risk would be addressed by conducting a comprehensive geotechnical assessment of the proposed site and by extensive seismic monitoring during development and testing.

Feasibility and Impediments to Growth

Although much has been accomplished in demonstrating the technical feasibility of HDR, several major issues must be resolved to reduce the real and perceived risks of developing commercial HDR ventures at other sites. These issues, primarily concerning engineering of the underground system, can be divided into the following categories:

Drilling and completion. Improvements in conventional and directional drilling techniques that lead to increased penetration rates and reduced costs would provide significant incentives for commercial HDR developments. Techniques and hardware are needed to isolate and control flow in multiple-fractured systems.

Reservoir stimulation. Improvements are needed for hydraulic fracturing in low-permeability reservoir rocks to yield interlinked injection and production wells with sufficient swept heat transfer areas and volumes to support commercial heat production rates for 10 to 30 years. Improved hydraulic fracturing requires improved geophysical diagnostic and analysis techniques for understanding in situ rock behavior.

Long-term reservoir performance. A commercial-scale stimulated HDR reservoir needs to be operated for one to two years to demonstrate reservoir performance and verify models being developed to predict performance. By April 1987, only limited testing of the second phase

reservoir at Fenton Hill had occurred. Although the results were positive, it is much too early to predict long-term performance. Further, the observed growth in reservoir volume with time needs to be better characterized.

Conclusions and R&D Budget Recommendations

Based on the preceding discussion, the following conclusions were reached:

- At this stage of the development, it is not known how large a fraction of the vast HDR resource could be economically converted into useful energy.
- HDR-produced heat and electricity are projected to be economic for some sites, given reasonable increases in petroleum prices and successes in reducing reservoir and drilling costs.

The following discussion and recommendations for DOE's R&D are based on the consensus of the Advanced Resources Program panel that reviewed the HDR components of DOE's LANL geothermal program in October 1986 (see Appendix G).

Although the current DOE program is well-managed, with reasonable and important technical goals directly addressing the issues raised in the previous section, program funding for HDR development at $8 million for fiscal year 1987 is at a critical threshold level for supporting current field efforts at Fenton Hill. There are no contingency funds if problems should develop at Fenton Hill and no funds for initiating field efforts at another site. To stimulate industrial development, DOE should be prepared to continue supporting HDR resource R&D through the demonstration stage (5 to 10 MWe) at Fenton Hill and at a second site.

Over the past 14 years, about $106 million of U.S. government funds and $32.5 million of combined West German and Japanese funds have been invested in HDR resource development, almost exclusively at the Fenton Hill site. As shown in Table 2-1, the budget for HDR has declined steadily from a high of $20 million in 1980 to its current value of $8 million in 1987. These funding cuts are further exacerbated by the recent loss of West German and Japanese financial support.

The specific program and budget recommendations for DOE HDR resource development are as follows:

- Fenton Hill testing. The second phase program at Fenton Hill should be completed with up to two years for reservoir testing and two years for analysis and modeling, documentation of results, and technology transfer. DOE commitment should end by 1991 and the site turned over to industry for second phase power plant development.
- Second site development. An industry partner should be secured for development of a second site. LANL technical staff should be involved to provide field engineering expertise as required. Support should be continued through the demonstration stage of a 5- to 10-MWe power plant.

Estimated required budgets for these two efforts over the next five years are shown in Table 2-3. With budget cuts to $8 million in fiscal year 1987 and the loss of technical personnel and $5 million in funds per year provided by West Germany and Japan, the program at Fenton Hill has been greatly weakened. Given the considerable investment of funds for HDR resource development and the promising results from preliminary testing of the second phase reservoir, it would be fiscally inappropriate not to see the project through this important field test. Contingency funds should be added to the budget for reworking the EE-2/EE-3 wellbores, if needed, since their operability is prerequisite for the flow test.

Because private commercialization of the HDR resource is the ultimate DOE objective, assuming favorable technical and economic factors, alternate site development will be required to establish sufficient confidence in the technology and costs to warrant private investment. Industry-government cofunded ventures should be vigorously pursued, but they may not be feasible in today's economic climate. Given HDR's potential critical role in U.S. long-term energy supply, DOE should be prepared to fund R&D efforts at the second site.

MAGMA ENERGY RESOURCES

Resource Description

Magma is molten or partially molten rock in the crust of the earth at depths usually greater than 3 km and at temperatures between 650° and 1,200°C. At these temperatures, the material is a mixture of liquid crystalline phases. Proposed magma energy extraction systems require drilling boreholes into convecting magma. The thermal stresses created in magma solidifying around the cooled borehole are believed to be sufficient to cause fracturing. By circulating a heat transfer fluid though the fractured and solidified magma, energy would be extracted from the magma.

Resource Base

A framework for estimating the spatial dimensions and heat content of magma chambers underlying recently active volcanic centers was provided by Smith and Shaw (1979). Based on their research, USGS published an estimated U.S. resource base of 50,000 to 500,000 quads of energy contained in magma chambers at temperatures above 600°C and at crustal depths in the range of 2.5 to 10 km. In spite of the uncertainty of these estimates, they indicate a large potential for magma energy. A significant portion may be economically recoverable. Sites have been identified in the western states where 30-year, multi-MW power plants could be supported by shallow magma bodies. Although considerable technology must be developed, magma resources are potentially significant for future U.S. energy supplies.

TABLE 2-3 Committee Budget Recommendations for DOE HDR Resource Research and Development (in millions of dollars)

	Fiscal Year					
Program Element	1987	1988	1989	1990	1991	1992
Fenton Hill testing	8	10	10	9.0	< 5	0
Second site development	0	2	15	15	25	15
Total	8	12	25	24	<30	15

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Current Status of Development

During 1983, the Geothermal Technology Division of DOE initiated the Magma Energy Extraction Project. This R&D program followed a seven-year scientific study funded by the DOE Office of Basic Energy Studies that demonstrated the scientific feasibility of the magma energy concept (Colp, 1982). Early research had been directed at a geophysical understanding of the location of magma bodies, the drillability and stability of boreholes at temperatures approaching rock melt, the chemistry of magmas, and heat transfer processes.

At the conclusion of the seven years of research, the energy extraction concepts were demonstrated by drilling into the molten zone of Kilauea Iki lava lake, Hawaii, emplacing energy extraction hardware into the borehole and operating the system over five days (Hardee et al., 1981). The energy extraction hardware consisted of an open heat exchanger system in which fluid was circulated through the solidified magma. This system appeared to promise high energy extraction rates.

The present magma energy program is focused on the U.S. continental magma systems. The magma project, managed by researchers at Sandia National Laboratories (Dunn et al., 1987), is addressing resource location and definition, drilling into magma, magma characterization and materials compatibility, and energy extraction. The objective of magma energy research is to drill into an active crustal magma body and conduct an energy extraction experiment. A location for the initial experiment has been selected in Long Valley volcanic crater in east-central California, where a reasonably shallow potential magma body has been identified.

Economic Issues and Projected Costs

Estimates of the costs of magma energy exploitation can be based only on reasonable projections. Of all the geothermal energy resources, magma has the least operational experience. Systems analysis indicates that the rate of energy extraction is the most important factor for economic use of magma energy. More specifically, it is the rate at which electricity can be generated from a magma well that is the major factor. Because all analyses are now based on several major assumptions, it is not possible to determine whether magma energy would be cost competitive with other energy resources. Current best estimates using detailed models of drilling, completion, surface conversion, and energy extraction are that magma-based electricity prices would be in the range of 80 to 110 mills/kWh (8 to 11 cents/kWh) (Carson and Haraden, 1985). These prices are somewhat higher than current prices of 50 to 70 mills/kWh for fossil fuels and 60 to 85 mills/kWh for hydrothermal geothermal resources. However, environmental, regulatory, and political constraints have driven prices for new nuclear plants above the magma estimates. As the technology is developed, the estimates should be improved and updated regularly. The technology developed in the magma energy program will surely benefit the evolving geothermal industry as a whole.

Environmental Concerns

The environmental issues associated with development of magma resources are similar to those for all geothermal resources. Thus, they are not reiterated here.

Feasibility and Impediments to Growth

The factors most critical to the technical and economic feasibility of magma energy extraction are well cost, well productivity, and reservoir lifetime. In particular, if it is economically and technically possible for a magma well to cost less than a half million dollars per megawatt of electrical capacity that it delivers, and if the well can be made to be productive for at least 10 years, magma-based energy would very likely be attractive.

Conclusions and R&D Budget Recommendations

Based on the preceding discussion, the following conclusions and recommendations were reached:

- The resource base of temperatures above 600°C provided by magma energy is extremely large. Nevertheless, technical exploitation is a long-term future possibility.

The DOE magma energy program should focus on developing techniques and methods for accomplishing resource location and spatial definition. Additionally, the program should be directed toward determining the engineering feasibility of extracting energy directly from shallow magma bodies and toward providing sufficient data for industry to evaluate its commercial potential. The program must develop drilling technology to reach the magma resource and completion technology to use the well for an extended period. It must also develop an energy extraction procedure that allows long-term efficient extraction of heat throughout a well's lifetime. The ultimate tests of extraction processes will be carried out by drilling into and verifying the existence of an active crustal magma body. This work might be done through the borehole proposed by Sandia for the Long Valley volcanic crater (in light of recent geophysical studies it is not yet clear that this is the optimal site). Current experimental and analytical investigations will be used to guide these field experiments and for data interpretation and evaluation. Recommended R&D levels of effort for accomplishing these goals are given in Table 2-4.

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

The large U.S. geothermal resource base indicates that even if only a small fraction can be economically converted into useful energy, it can be an important future energy source. This point is especially meaningful

TABLE 2-4 Committee Budget Recommendations for DOE Magma Energy Resource Research and Development (in millions of dollars)

	Fiscal Year				
Program Element	1988	1989	1990	1991	1992
Experimental and analytical investigations	0.5	2.0	2.0	3.0	3 0
Trial borehole	0.8	3.0	1.0	4.0	2.0
Total	1.3	5.0	3.0	7.0	5.0

insofar as the prices of other energy sources increase. Geothermal energy is inherently a secure energy source for the United States; it can be a baseload alternative to conventional fossil and nuclear power plants. Further, it can enhance air quality by reducing emissions from the burning of fossil fuels. Electric power is commercially produced from some hydrothermal resources, but commercialization of HDR, geopressured, and magma resources has yet to be demonstrated. Most environmental problems for hydrothermal power plants have been resolved, but some remain. The committee concluded that careful development and engineering should solve anticipated environmental problems.

Given the current U.S. energy situation, industry will continue developing technologies for hydrothermal resources. Because of the long-term horizon for their economic viability, industry will not support technical R&D for geopressured, HDR, and magma geothermal energy resources.

In the current DOE Geothermal Technology Program, HDR R&D dominates the budget at 38 percent; 19 percent is allocated to geopressured R&D and 14 percent to hydrothermal research. Only $1.4 million is earmarked for drilling technology, which cuts across all geothermal technologies. Another $1.3 million was set aside for reservoir engineering studies in the Salton Sea Scientific Drilling Project. The magma energy extraction program was reduced from $1.7 million in fiscal year 1986 to a half million in fiscal year 1987. The major areas of R&D are continuing, but the reduced hydrothermal research budget significantly affects these important projects.

Development of geopressurized brines requires improved understanding of reservoir size, dynamics, and productivity. Predictive models applicable to geopressured wells, under development for some time, require long-term flow tests and verification. Production well tests are encouraging, indicating that reservoir pressures are maintained considerably above levels predicted with conventional reservoir engineering techniques. However, before the long-term performance of a reservoir can be predicted on the basis of short-term tests, the driving forces that sustain the pressure must be confirmed.

The long-term environmental acceptability of geopressured resource exploitation must also be proved through long-term well tests before widespread development can be expected. Louisiana, for example, is already losing 50 square miles of coastline per year through natural subsidence, and additional subsidence attributable to geopressured wells probably would not be tolerated.

Similarly, verification of long-term reservoir performance is a principal technical consideration for HDR technology, along with control of water loss and circulation impedance and other technical features. For this technology to attract commercial development, the successful creation and control of a multiple-fractured reservoir of at least 20 to 35 MWt with a projected life in excess of 10 years must be demonstrated. Important field tests at the Fenton Hill site in New Mexico are under way.

Magma energy extraction R&D, new in advanced geothermal technology, has received only modest funding and is still in an early stage of development. Magma is the most difficult form of geothermal energy to

access, and the potential energy extraction rate is the controlling factor in its use.

Stable and well-funded R&D is needed to continue to determine and improve the scientific, engineering, and economic feasibility of using energy from all geothermal resource types. The short-term goal of the DOE R&D should be to improve technical performance significantly through research on second-generation technologies in order to locate, develop, extract, and convert geothermal energy from liquid-dominated hydrothermal reservoirs. Improved performance is expected to increase markedly the number of U.S. hydrothermal reservoirs from which industry can produce energy in the near term. These technologies are thus fundamental to a balanced DOE R&D program.

The longer-term goal of R&D should be to determine whether other types of geothermal resources (geopressured, HDR, and magma energy) are viable future energy sources and to continue to provide industry a base for evaluating the economics of producing and using these forms of energy. Because of their economics, it is unlikely that these resources will attract industry involvement in the short term. Given scientific and technical improvements from a continuing, well-funded federal R&D program, these four types of geothermal energy together offer a significant potential contribution to the economic and energy security goals of the United States.

Hence, the following conclusions were reached:

- The current oversupply and relatively low prices of hydrocarbon fuels, especially of petroleum, are short-term fluctuations within a long-term supply shortage. Given the large U.S. geothermal energy resource base and the potential for converting even a small percentage of this base into economically useful energy, developing U.S. geothermal resources may be an important contribution to U.S. energy self-sufficiency.
- In the near term, industry will continue to invest in technologies for exploiting hydrothermal resources. It will not invest in development for the longer-term resources of geopressured, hot dry rock, and magma energy. Because of the critical importance of maintaining various energy supply options for the future, a viable and stable research program for these longer-term geothermal energy resources is necessary.
- In the near term, the use of hydrothermal geothermal resources will exceed that of other geothermal resource types. Improving utilization technologies should make many of the presently uneconomic resources competitive. Power production from geopressured and hot dry rock resources is thought to be economic at some sites, although using these resources is a longer-term possibility. Magma energy technologies are too uncertain now to make economic projections.
- Significant strides in environmental controls for hydrothermal energy systems have been made since their early development. There has not been enough operating experience on other types of geothermal systems. Environmental problems remain but are site specific and are thought to be remediable through study, engineering design, and construction practices.

- The geographical distribution of geothermal energy resource fields is a constraint to use. The new high-temperature superconducting materials and their use for electrical transmission lines may alleviate this constraint.
- Institutional barriers are not a major constraint to geothermal energy development.
- Stable and adequately funded DOE R&D is needed to determine and improve the scientific, engineering, and economic feasibility of using energy from all types of geothermal resources. Short-term R&D in the DOE geothermal technology program should be directed toward improved technologies to locate, develop, extract, and convert geothermal energy from liquid-dominated hydrothermal resources.
- Long-term DOE R&D should be directed toward determining the viability of geopressured, HDR, and magma energy resources for future energy production. Expenditures in these areas can decrease in the future as commercial viability is or is not indicated and industry accordingly begins to participate.

The following recommendations were therefore reached:

- The DOE Geothermal Technology Program should be funded over a five-year period at a somewhat higher and stable level to maintain viable R&D programs for both near-term and long-term geothermal resources (see Table 2-5). The funding recommended for each geothermal resource category is at a critical minimum level, and would decline over the period as anticipated research goals are met (see Tables 2-2 to 2-4).

TABLE 2-5 Committee Estimates of the DOE Budget Needs for Geothermal Resources Research and Development (in million of dollars)

	Fiscal Year				
Program Area	1988	1989	1990	1991	1992
Hydrothermal	16.7	16.7	16.7	14.2	14.0
Geopressured	7.0	7.0	7.0	7.0	7.0
Hot dry rock[a]	10.0	10.0	9.0	< 5.0	0
Magma energy	1.3	5.0	3.0	7.0	5.0
Total	35.0	38.7	35.7	33.2	26.0

[a]Does not include development of a second site (see Table 2-3). Funding levels for each category are at a critical minimum.

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GOVERNMENT, INDUSTRY, AND UNIVERSITY COOPERATION IN GEOTHERMAL RESOURCE DEVELOPMENT

In the United States and other countries, cooperation among government agencies, industrial companies, and universities has taken different forms over the years. Many models of such cooperation exist, and they are described here. Certain characteristics of cooperative organizations strongly influence their ability to meet their goals. This chapter examines these characteristics as they apply to developing both near- and long-term geothermal resources.

Cooperative arrangements were discussed at length at the workshop sponsored by the committee (see Appendix B). Presentations by the speakers and comments by the advisory group helped the committee in its deliberations.

BACKGROUND

Nearly all models for cooperative research and development (R&D) the committee reviewed have common elements, largely because organizations brought together to effect this R&D have had to wrestle with common issues. The committee recognized that even though most cooperative organizations experience like problems, important differences often determine successes and failures. Sometimes the differences are obvious and at other times they may be subtle. For example, the quality of dialogue among participants may be critical to successful and sustained operation.

Each participant in a cooperative effort may have quite different motivations. A federal agency may attempt to carry out a congressional mandate through a cooperative mechanism involving industry and universities. A private company may attempt to accelerate the development of a needed technology and be willing to share ownership of the technology in return for early access. A university faculty member may be seeking funding of a research project in return for sharing ownership of a patent with the sponsors.

In the United States, there is currently a strong interest in promoting cooperative government-industry-university relationships. This interest appears to be driven by several factors: tightened or reduced federal and industrial R&D budgets, aggressive foreign competition strengthened by increased government-industry cooperation, a need to share expensive facilities and equipment, changes in the antitrust laws and their interpretation that facilitate cooperation among private companies, and a belief prevalent in many circles that the results of university research often languish in the laboratory too long without being applied.

The major attraction of cooperation is that participants can share the costs and the financial risks. In addition, participants are exposed to a broader technical base. Joint ventures among private companies, as a means for the companies to take on projects that would be too large or risky for them individually, are common and well-accepted. By cooperating in R&D, government agencies and private companies can generally leverage their investments and participate in efforts of broader scope than they can afford individually. Collaboration in R&D can also lead to shared access of specialized facilities and equipment that a single party cannot afford.

With increasing national concern about U.S. competitiveness, there is the growing belief that more commercial advantages should flow to U.S. companies from public and private investments in research. By the same reasoning, involvement of industry in university-based research should increase the relevance of research to industry needs. Several notable federal R&D programs now require some industrial participation, at least in planning and technology transfer, in the university-based R&D centers that they fund (see the following sections on government-industry and government-industry-university cooperation).

Another advantage for participants in cooperative organizations is that the interchange improves understanding of activities in other laboratories, subject of course to reasonable protection of proprietary interests. Such collaboration seems to have improved communication among managers and professionals involved in the joint efforts.

Even so, tradeoffs arise from participating in cooperative organizations. Participants must share control and ownership of intellectual properties, where applicable. One potential problem is that cooperative efforts may unduly expose a company's proprietary information to its competitors. In addition, a cooperative organization may simply create another layer of bureaucracy between the sponsoring and performing parties, often adding unnecessary overhead.

The chapter ends by examining the feasibility of two cooperative arrangements. They concern the near-term technical needs of hydrothermal resource development and an improved scientific basis for developing longer-term geothermal resources.

EXAMPLES OF COOPERATIVE RELATIONSHIPS

Numerous organizations bring industry, universities, and government together to pursue joint R&D. Such arrangements have been described in detail (National Research Council, 1986a,b; Gray and Lorand, 1986), but a few of the more exemplary will be outlined here. The discussion is limited to consortia for conducting engineering R&D and does not include either medical or agricultural R&D efforts.

Industry-Industry Cooperation

The Microelectronics and Computer Corporation (MCC), the Electric Power Research Institute (EPRI), and the Gas Research Institute (GRI) are well-known. All are corporations, with a board of directors, that set research goals, outline projects, and have permanent staffs to arrange for research. For some, research is arranged with both public and private organizations; others, such as MCC, have internal resources for conducting research. Its source of funds is industry. In all cases, industry is the principal beneficiary of the research. However, EPRI and GRI are funded by the electric and gas utilities, respectively, through a rate structure that allows a part of the income earned by utilities to be diverted in support of these institutes.

Industry-University Cooperation

Industry-university cooperation generally falls into three categories. The first is the traditional "industry affiliates" program, as pioneered by MIT, in which companies with common research interests pay as much as $25,000 to $50,000 per year to help support a research program of fairly limited scope, for example, on composite materials. In return, sponsors are kept informed about the research. The scope and direction of research are largely determined by a professor or a group of academic researchers.

Another traditional mechanism is a single company's contracting with a university for research of specified scope or its making a grant to a university for research in an area of mutual interest.

A third type of industry-university cooperation is exemplified by the Semiconductor Research Corporation (SRC), in which a group of companies interested in a well-defined research area form a corporation to support university research. The corporate board provides funds and with outside assistance decides on projects and centers to be supported.

Government-University Cooperation

Government-university relations are well-established; many cooperative organizations have been operating for up to 40 years. They range from large laboratories for the Department of Defense, such as the Johns Hopkins Applied Physics Laboratory and Pennsylvania State University's

Applied Research Laboratory, to companies with small contracts for specific studies.

There are many other examples of government-encouraged cooperative efforts, such as the National Science Foundation (NSF) support of laboratories or scientific projects directed by a consortium of universities, for example, the University Corporation for Atmospheric Research.

Government-university cooperation represents all kinds of financing and project direction. In military contracts, research is usually 100 percent government financed, and the direction of the research, at least in general terms, is usually defined explicitly. In NSF contracts and grants, on the other hand, the university is expected to make a financial contribution, but the academic researchers have much more scientific and technical control.

Government-Industry Cooperation

Government contracts with a single company require no elaboration, but there are also arrangements between government agencies and a consortium of companies. One example of this arrangement is the Geothermal Drilling Organization (GDO)-DOE agreement, which is discussed in detail later. Another example is the cooperation between the National Bureau of Standards' Advanced Manufacturing Research Facility and its industrial cooperators. In these arrangements, funding often comes from both government and industry, which together decide the projects to support. The projects may be carried out in either industrial or government facilities.

Government-Industry-University Cooperation

The third and generally most complicated type of arrangement involves government, industry, and universities. Nevertheless, such arrangements are now in favor because it is believed that they can concentrate on matters of national importance and can move research results more quickly into the market.

Examples include the Engineering Research Centers and cooperative R&D centers sponsored by NSF. Located at universities, the centers must have a significant source of outside funding (e.g., private companies and state governments). Although the direction of the research projects is the responsibility of the university researcher, industrial advice is sought in guiding the program toward satisfying industrial needs.

Role of Limited Partnerships

The committee also considered the possible role of limited partnerships in either short- or long-term geothermal resource development. Because of the recent changes in the U.S. tax law, the attractiveness of the R&D limited partnership (RDLP) to raise capital for R&D has diminished

considerably. The committee understands that, beginning in 1987, the tax benefits for investors from RDLPs will be greatly reached (Peter and Fusfeld, 1986).

Consequently, decisions by private investors to engage in RDLPs are now driven by a project's inherent profit potential and also by the convenient legal structure of an RDLP, rather than by tax advantages (Peters and Fusfeld, 1986). Given the present (and likely near-future) energy price structure, the committee concluded that such partnerships in geothermal R&D will not offer enough profit potential to serve as a new source of R&D funding.

QUESTIONS ABOUT COOPERATIVE RELATIONSHIPS

On examining the variety of cooperative relationships organized to plan, manage, and perform R&D, the committee found that all appear to have addressed common issues. In the design of a cooperative R&D organization, confronting these issues is essential to an operationally successful cooperative relationship.

The committee identified 15 specific issues that must be resolved:

1. Goals and objectives. Which of the partners determines the organization's goals and objectives? Are they determined by the industrial, government, or university partner? How broad or narrow are the goals and objectives?
2. Research agenda and program. How is the research agenda determined? Who is involved in this process? Does the government partner actually set the agenda or does it just have the right of approval? If companies provide funds, is it their agenda? What is the role of academic researchers, who are also often partners, in agenda-setting?
3. Financing. How is the organization financed on a short-term basis? What is the role of membership fees? Is there base financing as well as project financing? How is the "overhead" infrastructure financed? What are the relative roles of private and public financing? How much should come from the federal government, industry, and state government?
4. Program and project management. Who is responsible for managing the organization's programs? Who manages the projects? Are these tasks the responsibilities of the organization, the funding agency, or the research partners?
5. Ownership and use of intellectual property. Who owns the results of research that have tangible market value (such as patents, data bases, and software)? Is income from the sale or use of intellectual property shared, and if so, how? How is proprietary information handled? What rules govern lead time and dissemination of research results through publication?
6. Research performance. Who actually performs the research, universities, industry, or government? Must the performers be members of the cooperative organization? Are the performers staff members of the organization, or is their work done under contract?

7. Evaluation. How is the general performance of the organization evaluated? Who carries out this evaluation, using what criteria? How is evaluation of proposed research accomplished and performers selected? Are these tasks done by peer or management review? How is the quality of research performance measured? How is responsibility delegated?

8. Accountability. To whom is the cooperative organization accountable, government, industry funders, or a board selected by the funders?

9. Collaboration and cooperation. Is interinstitutional collaboration desired? If so, how is it brought about? What is meant by collaboration as opposed to cooperation on research projects?

10. Antitrust implications. Are antitrust implications raised by the organization's structure, operations, or meetings? Are there any monopoly implications? What about the appearance of monopolistic practices?

11. Institutional structure. How is the cooperative relationship structured? Does it have to be a new organization, or can it rely on an existing one? Is the organization an independent cooperation, joint venture, or partnership? What kind of board of control is appropriate, and how is it appointed? What are membership requirements? Is there a chief executive officer for the organization?

12. Administrative support. Is a new administrative infrastructure required for the organization, or can an existing infrastructure be used to provide administrative services? How are administrative costs (overhead) accounted for and paid?

13. Program integration. How are performance and results of the organization's research activities transferred into the life of cooperating institutions?

14. Employment factors. How are officers and staff members employed, on a short- or long-term basis? Do they have to sever their ties to preceding employers?

15. Educational implications. What are the opportunities for or constraints on employees with respect to continuing education and training?

CRITERIA FOR SUCCESS IN COOPERATIVE RELATIONSHIPS

In general, the committee concluded that success and failure in cooperative organizations are rooted as much in the subtleties of the relationships as in the structures, in the quality of the dialogue among participants, and in the degree of commitment they bring to achieving the goals of an organization. However, the organization and its structure will either facilitate or retard progress. Thus, several criteria stand out as critical and require resolution through design:

- Where does program direction and control reside? If the goal is commercial application, then the industry partners must control program direction. If increasing the knowledge base is the goal, then the university partner must control program direction. To help understand the broad range of approaches that can be taken on program direction, the

committee considered the examples in Figure 3-1, which shows a selected number of existing cooperative organizations. At the extreme top is the MCC, which is funded and controlled exclusively by private industry. EPRI and GRI are predominantly controlled by industry, but because of the regulatory review process, their programs are also influenced by government and universities. At the lower right corner, government laboratory cooperatives have varying degrees of outside direction. As one example, the National Bureau of Standards' Advanced Manufacturing Research Facility receives substantial funding from the U.S. Navy, but it also involves a significant number of private companies.

In the lower left corner are the cooperative university programs, such as the National Science Foundation Centers mentioned earlier. Even though the majority of the funding for these centers comes from government, control is exercised largely by faculty researchers. The influence of industry varies, depending on both the fraction of support provided by industry and the working relationships between industrial and university players.

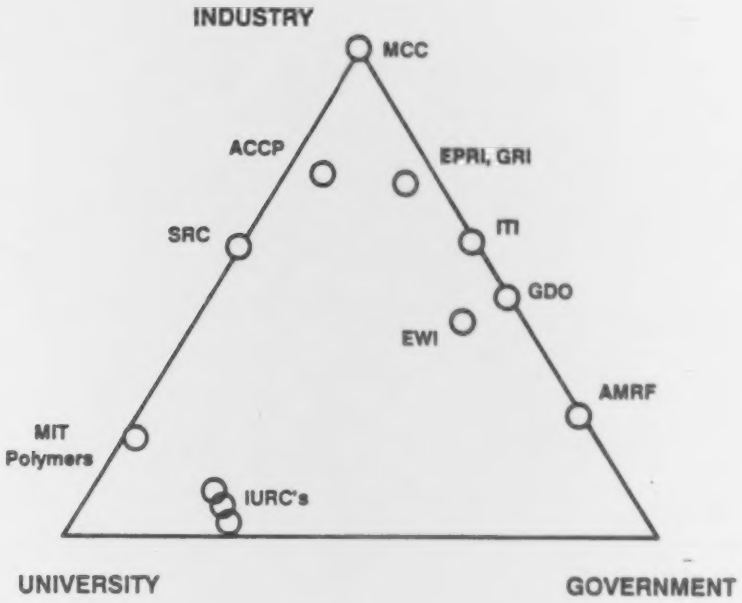
o Is there a sufficiently long-term commitment by the partners? Without a multiyear commitment to the organization and its goals by participants, long-term planning is impossible. Commitment in this case is not meant to imply long-term financial commitment, because this is legally or structurally impossible for some participants. However, in its more subtle meaning, commitment to a cooperative relationship implies the desire by participants to stay with it. It also suggests the belief that the success of the individual participating organizations is related to the success of the cooperative organization. The implication, then, is a long-term financial commitment.

o Are adequate resources available to achieve the objectives (or can these resources be developed)? Objectives unachievable owing to insufficient resources are the fastest and surest way to destroy relationships.

o Can and do the participants communicate well with one another? For an arrangement to succeed, open, unambiguous communication is an essential ingredient. If the partners do not start with basic trust and experience in communicating with one another, then the structure and operations of any partnership will not work. Good, strong leadership can help overcome communications problems, but long-term success is tied to cooperation through open communication among participants.

ALTERNATIVE APPROACHES TO COOPERATIVE RELATIONSHIPS

Because of current economic conditions and the state of development in the geothermal industry, the committee concluded that it is unrealistic to expect that private industry can or will fund most of the R&D needed in this area. The short- to mid-term profit potential is not sufficiently high, and the industry is not mature enough to generate the profits needed to support significant R&D. Industry-university cooperation such as an industry affiliates program or the SRC are, thus, unlikely in geothermal



ACCP	Advanced Ceramics & Composites Partnership, Midwest Technology Development Institute
AMRF	Advanced Manufacturing Research Facility, National Bureau of Standards
EWI	Edison Welding Institute (Ohio)
EPRI	Electric Power Research Institute
GDO	Geothermal Drilling Organization
GRI	Gas Research Institute
ITI	Industrial Technology Institute (Michigan)
IURCs	Industry University Research Centers, National Science Foundation
MCC	Microelectronics and Computer Corporation
MIT/Polymers	Massachusetts Institute of Technology, IURC
SRC	Semiconductor Research Corporation

FIGURE 3-1 Program Control of Cooperative R&D Organizations.

R&D. Nor could an organization like MCC or EPRI be supported; limited partnerships do not offer enough profit potential to serve as a new source of R&D funding. Consequently, the government must continue to sponsor R&D if substantial progress is to be made.

Government-Industry Cooperation for Near-Term Resource Development

After reviewing various cooperative mechanisms for near-term geothermal resource R&D, the committee concluded that one model stood out above all others--the existing cooperative agreement between the Geothermal Drilling Organization and the Department of Energy (DOE).

Though the objective of the agreement is presently limited to developing technology for reducing the cost of drilling, completing, and logging geothermal wells in the short-term and the organization is not without shortcomings, GDO is an apparently successful operation that responds to most issues raised earlier and generally meets the criteria for success.

GDO membership is open to all (businesses, universities, individuals, and others). It has 18 members, each of whom paid an initial $500 membership fee. The organization sets priorities for short-term R&D projects and seeks funds from its members as well as matching funds from DOE. Each project is funded by individual firms and DOE. For equipment that is developed, the funders have priority use for one year and royalty-free licenses thereafter. Anyone may use the equipment after the first year.

Sandia National Laboratories, acting as project administrator for GDO and DOE, contracts with outside performers project by project. Three projects are now under way and more are being developed. The principal elements of this arrangement are the following:

- Projects have well-defined, short-term objectives.
- GDO members select the projects, if any, they wish to support.
- DOE reserves the right to select which GDO-proposed projects it wishes to support.
- DOE support for projects can be approved through a prior legal agreement ("Project Letter Agreement") without having to renegotiate each time. This agreement is the heart of the GDO-DOE model.
- All funds (both industry and DOE) flow into Sandia National Laboratories, which serves as the contracting agent for the agreement.
- The projects are performed by outside parties under contract to Sandia.

The committee concluded that this arrangement is a successful and effective model that should be modified and then adapted to cover the wide range of short- through mid-term cooperative geothermal development activities. The committee is aware of several other organizational initiatives to rationalize government-industry geothermal development projects. In light of the success of the GDO model, the committee

recommends expanding its charter from "geothermal drilling" to "short- to mid-term geothermal development." Correspondingly, the organization's name should be changed from the Geothermal Drilling Organization to the Geothermal Development Organization. The committee recommends consideration of other changes in structuring the new GDO:

- o Organizing as an independent membership corporation capable of owning assets
- o Developing a board of directors and officers that does not include DOE or DOE contractors (as Sandia does)
- o Adding a small permanent staff, including an executive director, to serve as a secretariat and fiduciary agent.

Government-University Cooperation for Research on Long-Term Geothermal Resources

In considering alternative cooperative mechanisms for research on long-term geothermal resources, the committee concluded that several facts must be confronted. Industry will probably continue to invest in near-term hydrothermal resource development, but they will probably invest little, if any, for research on long-term resources. In particular, there is a low probability of industrial funding for geoscience research (and related technologies) on geopressured, hot dry rock, and magma geothermal resources.

Because of the critical importance of ensuring various future energy supply options, a minimal long-term research program on potential sources, such as geopressured, hot dry rock, and magma resources, must be pursued.

Drawing in part from the review of the GDO-DOE agreement and from assessment of other cooperative organizations, the committee concluded that one approach for long-term government-university cooperative research should be considered a promising policy option.

The first element of this government-university cooperative relationship would be the establishment of a Geothermal Research Organization (GRO) composed of researchers interested in the scientific and technological issues relating to long-term geothermal resources: geopressured, hot dry rock, and magma resources. Even though GRO's main purpose initially would be to advise government agencies and formalize communication among primarily academic researchers, GRO should be incorporated. Incorporation could occur if and when GRO decides to own intellectual properties or act as a financial agent for participants.

Second, GRO participants, in cooperation with government funding agencies, would agree to develop a research agenda. This agenda would include both a multiyear program plan and specific research projects. Within the framework of this agenda, the researchers, individually or in collaboration, would then submit proposals to the contract administrator, who in turn would subject the proposals to rigorous peer review and ranking for importance and timeliness.

Third, DOE would allocate part of its long-term research budget to these efforts on a sustaining basis. Funds would be transferred to the

contract administrator for disbursement to GRO participants. Sandia Laboratories could, of course, be one contract administrator, although other DOE laboratories and operational organizations could do so. The committee decided, however, that the contract administrator should not perform any research funded through this mechanism, that is, should not compete with universities and other eligible performers for funds.

Fourth, both DOE and the GRO participants would work together to identify other funding sources, primarily from the federal government, who might be interested in investing in program areas and projects compatible with a particular agency's mission. Candidates include the NSF, U.S. Geological Survey, and Department of Defense. As a practical matter, such efforts could be funded by a consortium of government agencies, an approach that has worked for certain interdisciplinary problems in the past. One specific mechanism considered by the committee was the funding of such work through an Engineering Research Center sponsored by NSF and funded by several federal agencies. For example, DOE and other agencies could transfer money to NSF for the support of such a center. The committee noted that NSF would have to be flexible in its review of a GRO-endorsed center, providing specifically for involvement of a number of universities in the center's activities.

It is even possible that, if the profit margins of the large oil companies improve with increased oil prices, some oil companies might invest in basic geoscience research of general relevance to oil and gas exploration and production. A geothermal-oriented research center, which encourages industry involvement, might attract such funding.

Further, a "geothermal coordination group" could be composed of an equal number of representatives from the GDO and GRO. The purpose of this group would be to keep the two organizations aware of each other's activities, share information, provide a bridge between government-industry and government-university cooperative efforts, and speak for the broader interests of those involved in geothermal R&D.

The committee concluded that an organization such as GRO would serve as an excellent means of coordinating both the relatively small number of academic researchers working on long-term geothermal research and the large number of scientists working in allied fields. With a long-term commitment of DOE and other federal funding, significant progress could be made in understanding the nature of the advanced geothermal resources and the prospects for long-term economic development of those resources.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions:

Given the existing economics of energy and the state of the U.S. geothermal industry, the Geothermal Drilling Organization is judged to be the best approach to short-term drilling R&D and should be modified to address short- to mid-term geothermal development.

Recommendations:

- The charter of the GDO should be expanded from its current coverage of "geothermal drilling" to "short- to mid-term geothermal development." The GDO's name should be changed to the Geothermal Development Organization and a restructuring implemented.

- A Geothermal Research Organizaiton should be formed, composed of researchers interested in the scientific and technological issues in developing long-term geothermal energy resources: geopressured, hot dry rock, and magma energy. This organization would serve as an excellent means of coordinating the relatively small number of academic researchers working on these long-term resources and the large number of scientists working in allied fields.

APPENDIX A

STATEMENT OF TASK

1. Review the U.S. geothermal goals and the DOE program. Identify the nonprice constraints to geothermal as a future energy source, in particular, environmental, land use, and public utility concerns.
2. Identify and prioritize the major technical, economic, environmental, and institutional issues in developing geothermal energy resources.
3. Review current DOE Geothermal Energy Technology Program efforts to cooperate with industry, academia, and other parts of the government, in light of the above, and the strategy of greater reliance on and interaction with private companies and university researchers.
4. Plan and conduct a two-day workshop at which industry, government, and university panels of experts will discuss major issue areas and give their views on the role of DOE's Geothermal Energy Technology Program in cooperating with other sectors: academia, industry, and other parts of the government. The panel members will review current cooperative efforts, suggest opportunities and mechanisms for enhanced cooperation, and join the committee in a discussion of the benefits and limitations of the various mechanisms over the near and long terms.
5. Compare the issues identified by the committee with the issues currently addressed by DOE's Geothermal Energy Technology Program, especially as they affect the program's cooperative links with universities, industry, and other parts of the federal government.
6. Develop two scenarios for cooperation with industry, academia, and government. The first scenario will take the current geothermal R&D program and goals, as given, and consider optimal cooperative activities with the other sectors at alternative funding levels. The second scenario will assume a modified program structured around the major issues given priority by the committee and consider optimal cooperation with the other sectors at alternative funding levels. In each case, the committee will identify a range of options that could improve the industry-government-university R&D infrastructure germane to geothermal energy.
7. Prepare a report of the study.

APPENDIX B

GEOTHERMAL ENERGY WORKSHOP:
R&D AND COOPERATIVE ARRANGEMENTS

Monday, February 9-10, 1987
National Academy of Sciences
Joseph Henry Building, Room 455
2100 Pennsylvania Avenue, N.W.
Washington, D.C. 20418

AGENDA

Monday, February 9, 1987

8:00 a.m.	CONTINENTAL BREAKFAST
8:30 a.m.	OPENING REMARKS AND INTRODUCTIONS Dennis F. Miller, Executive Director Energy Engineering Board Norman Hackerman, Chairman, Committee on Geothermal Energy Technology Program
8:45 a.m.	RECOMMENDATIONS FOR DOE'S GEOTHERMAL TECHNOLOGY PROGRAM: A FIVE-YEAR PERSPECTIVE Carel Otte, President, Geothermal Division, Unocal Corporation
9:45 a.m.	DISCUSSION
10:10 a.m.	GEOTHERMAL ENERGY-ENVIRONMENTAL ISSUES Hamilton Hess, Geothermal Coordinator, Sierra Club
10:40 a.m.	OPEN DISCUSSION
11:00 a.m.	INDUSTRY/UNIVERSITY COOPERATIVE EFFORTS Alex Schwartzkopf, National Science Foundation
11:20 a.m.	COOPERATIVE ARRANGEMENTS: SOME EXAMPLES Alan Schreisheim, Director, Argonne National Laboratory
11:45 a.m.	OPEN DISCUSSION
12:15 p.m.	LUNCH
1:00 p.m.	JOINT RESEARCH AND DEVELOPMENT VENTURE: A CASE STUDY Michael Lee McQueen, Assistant Council, Unocal Corporation

1:30 p.m.	OPEN DISCUSSION
1:50 p.m.	JOINT INDUSTRY/DOE R&D: SUCCESSES, CONSTRAINTS AND OPPORTUNITIES Richard Traeger, Department Manager Exploratory Energy Systems Sandia National Laboratories
2:20 p.m.	OPEN DISCUSSION
2:40 p.m.	JOINT UNIVERSITY/INDUSTRY COOPERATION Pete Mayfield, Director, Cross Disciplinary Research, National Science Foundation
3:00 p.m.	OPEN DISCUSSION
3:30 p.m.	BREAK
3:45 p.m.	COOPERATIVE ARRANGEMENTS AMONG INDUSTRY/GOVERNMENT/ UNIVERSITIES WITH RESPECT TO ELECTRIC UTILITIES Vasel Roberts, Program Manager Geothermal Power Systems Electric Power Research Institute
4:15 p.m.	OPEN DISCUSSION
4:35 p.m.	THE FINANCIAL CLIMATE AND COOPERATIVE ARRANGEMENTS William Short, Vice President Kitter Peabody Incorporated, New York
5:05 p.m.	OPEN DISCUSSION
6:00 p.m.	SOCIAL HOUR
7:00 p.m.	DINNER
8:30 p.m.	THE IMPENDING U.S. ENERGY CRISIS Robert Hirsch, Vice President, ARCO Oil and Gas Company

Tuesday, February 10, 1987

8:00 - 11:00 a.m.	DISCUSSION BETWEEN COMMITTEE AND SELECTED SPEAKERS AND MEMBERS OF ADVISORY GROUP ON COOPERATIVE ARRANGEMENTS

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ATTENDEES

Committee Members

Norman Hackerman, Chairman
The Robert A. Welch Foundation

James B. Combs
Geothermal Resources International, Inc.

Myron H. Dorfman
University of Texas

Wilfred A. Elders
University of California

Stephen J. Gage
Midwest Technology Development Institute

Robert G. Lacy
San Diego Gas & Electric

Carel Otte
Unocal Corporation

Martin Robbins
Colorado School of Mines

Jefferson W. Tester
Massachusetts Institute of Technology

Eric A. Walker
The Pennsylvania State University

Presenters

Hamilton Hess
Sierra Club

Robert Hirsch
ARCO Oil and Gas Company

Pete Mayfield
National Science Foundation

Michael Lee McQueen
Unocal Corporation

Carel Otte
Unocal Corporation

Vasel Roberts
Electric Power Research Institute

Alan Schreisheim
Argonne National Laboratory

Alex Schwartzkopf
National Science Foundation

William Short
Kitter Peabody, Inc.

Richard Traeger
Sandia National Laboratories

Advisory Group

Daniel Cubicciotti
Electric Power Research Institute

Lansing Felker
U.S. Department of Commerce

Herbert Fusfeld
Rensselaer Polytechnic Institute

Robert Hirsch
ARCO Oil and Gas Company

Tom Hogan
National Science Foundation

Harold Hubbard
Solar Energy Research Institute

Richard Nelson
Columbia University

Tom O'Hare
Brookhaven National Laboratory

Manik Talwani
Houston Area Research Center

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MEETING OF THE COMMITTEE ON
GEOTHERMAL ENERGY TECHNOLOGY PROGRAM

February 10, 1987 (Tuesday)

8:30 a.m.	DISCUSSION OF WORKSHOP Identify Major Points Identify Any Missing Considerations Agree on Conclusions and Recommendations Writing Assignments for Report Write Rough Draft of Report
10:15 a.m.	BREAK
10:30 a.m.	CONTINUATION OF MEETING Writing Sessions
12:00 noon	LUNCH
1:00 p.m.	CONTINUATION OF MEETING
5:00 p.m.	ADJOURNMENT

February 11, 1987 (Wednesday)

8:30 a.m.	CONTINUATION OF PREVIOUS DAY Writing Sessions Review of Written Sections Identification of Missing Parts Writing Assignments and Deadlines for Completion of Final Report
5:00 p.m.	ADJOURNMENT

APPENDIX C

CONVERSION TECHNOLOGIES FOR POWER GENERATION

Three basic concepts for conversion technologies are being used to produce electric energy from hydrothermal resources. The many versions of these conversion systems need to be examined for each application. They have reached their present state of evolution with varying levels of federal funding.

DRY STEAM SYSTEM

The dry steam system conversion technology is used at The Geysers. The system is based on conventional power plant steam technology adapted and perfected by private industry for use here. Figure C-1 is a simplified schematic diagram of a dry steam system.

Dry, slightly superheated steam from the production wells operates a condensing steam turbine that in turn drives a generator. The exhaust steam is condensed in a direct contact condenser, and the condensate is used as makeup to a mechanical draft cooling tower. Cooling tower blowdown is usually reinjected.

Dry steam-conversion technology has been considered commercially available by the geothermal and electric utility industries for many years. This technology is attractive and economically competitive, but dry steam hydrothermal reservoirs are rare.

SINGLE AND DOUBLE FLASH SYSTEMS

Single and double flash system conversion technology is being used increasingly on high-temperature (above 180°C [350°F]) water-dominated reservoirs. These systems are based on old (early 20th century) steam plant technology. Equipment and techniques for separating clean steam from geothermal brines and handling the highly saline brines have been the targets of extensive R&D efforts by both industry and the federal government.

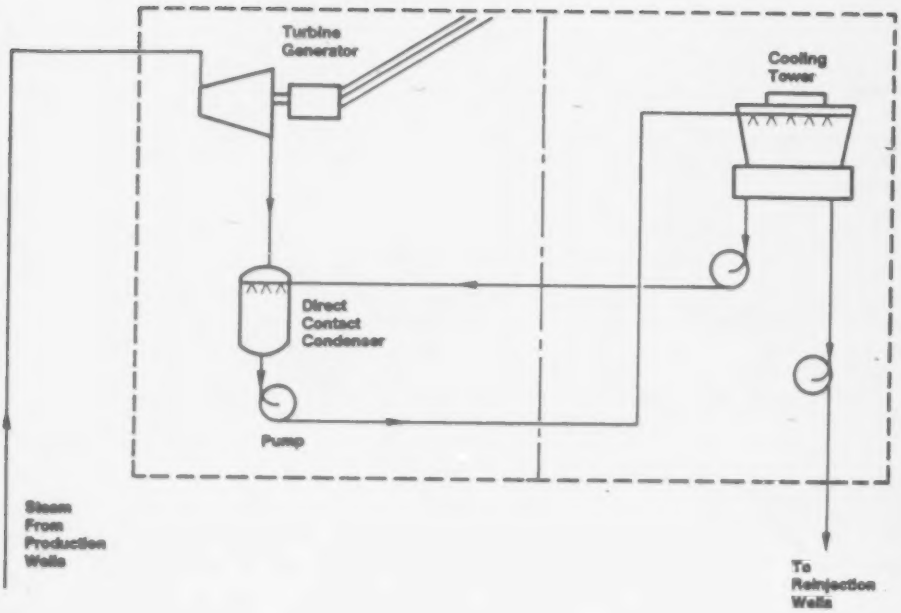

FIGURE C-1 Schematic Diagram of a Dry Steam System.

SOURCE: Kestin et al. (1980).

In this country, research and development in the use of liquid-dominated resources for power generation began with experiments in the Imperial Valley of California at the Salton Sea in 1972. These experiments were followed in 1976 by completion of the DOE Geothermal Loop Experimental Facility, the first cooperative, jointly funded government-industry geothermal demonstration facility. Its purpose was to determine the technical and economic feasibility of generating electricity with highly saline brines. The most significant success of this venture was development of the reactor-clarifier brine treatment system, which, with more recent industry modification, permits the use of these brines in several power plants today. A simplified schematic diagram of a single flash system is presented in Figure C-2. In this system, the production wells are permitted to flow spontaneously, resulting in a two-phase mixture of liquid brine and steam at the surface (this is known as flashing). The mixture is routed to a separator, and the separated scrubbed steam operates a condensing steam turbine, that in turn drives a generator. The separated brine is reinjected. The condensed steam is often used as makeup to a mechanical draft cooling tower. Cooling tower blowdown may be reinjected.

A double flash system involves the flashing of the separated brine a second time to produce additional steam at a lower-pressure. This lower-pressure steam is used to operate a separate steam turbine or is introduced into the high-pressure turbine through a second admission point.

Single and double flash systems are in commercial service today in the United States. However, their use is limited to high-temperature resources. The high capital cost of these systems, if installed on moderate-temperature resources, makes them uneconomical until the cost of the resource development can be reduced.

BINARY CYCLE SYSTEM

Binary cycle technology is the preferred alternative for developing liquid-dominated reservoirs that are not hot enough for efficient flash steam production but that contain enough heat to evaporate an organic working fluid in the 105° to 200°C (200° to 400°F) temperature range. Some small (< 13 MWe) binary power plants are in commercial service in the United States (see Appendix F). A simplified schematic diagram of a binary cycle system is presented in Figure C-3.

In the binary cycle steam, the hot brine is pumped from the reservoir to avoid flashing and two-phase flow. The brine yields its energy in counterflow heat exchangers to a working fluid with a low boiling point. The working fluid may be a fluorocarbon, a hydrocarbon such as isobutane or pentane, or a mixture of similar substances. The working fluid, which is vaporized in the heat exchangers, operates a turbine that in turn drives a generator. The exhaust vapor is condensed in a surface condenser, which is cooled with water from a mechanical-draft cooling water.

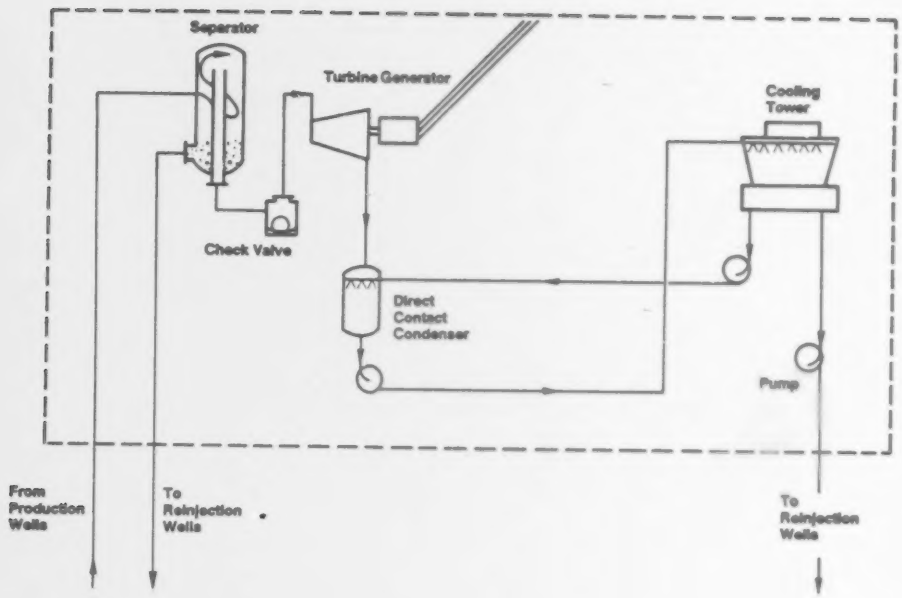

FIGURE C-2 Schematic Diagram of a Single Flash System.

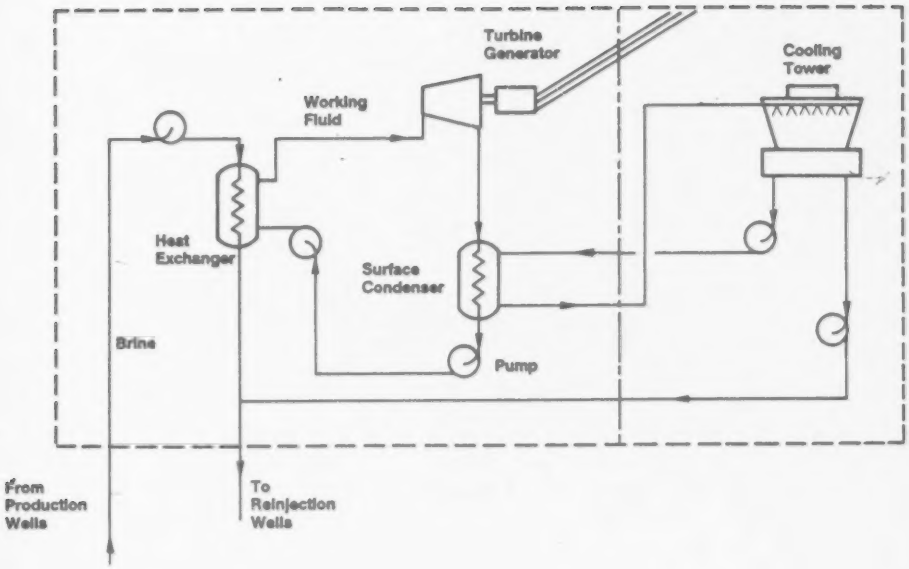

FIGURE C-3 Schematic Diagram of a Binary Cycle System.

SOURCE: Kestin et al. (1980).

The importance of a commercially viable binary cycle conversion system to the geothermal industry and the nation stems from its broad applicability. Approximately 80 percent of the hydrothermal resources in the United States are moderate-temperature resources that can be developed economically only with this technology. These reservoirs represent 50 percent of the potential electric generation from hydrothermal resources. Fully 40 percent of electric generation from future plants on geopressured reservoirs will probably be produced by binary cycle conversion systems. The balance will be produced by methane engines and pressure reduction systems. Further, all electric generation from hot dry rock reservoirs must be produced by binary cycle conversion systems.

Direct Heat Utilization

Because of the relatively low temperatures of geothermal fluids (typically 100° to 300°C), nonelectric direct uses are frequently attractive for geothermal systems. These include industrial process heat applications in which geothermal fluids might be used to generate steam or hot water needed to supply heat to a manufacturing operation. For example, in the paper industry, large quantities of steam are required for pulp digestion and paper drying at temperatures ranging from 150° to 100°C. Space heating applications for geothermal heat are widespread, with suitable temperatures of 70° to 100°C. Examples in the United States are found at Klamath Falls, Oregon, and Boise, Idaho, and worldwide, in Iceland and the USSR. Even lower geothermal fluid temperatures (< 50°C) can be upgraded by heat pump design. Examples are found in Auburn, New York, and in France.

One economic advantage to process heat applications is the inherently large load factors of many industrial processes. Space heating applications are less attractive because of lower load factors. Substantial use of geothermal energy for space heating in the United States will require extensive and costly retrofitting.

Cogeneration is sometimes well-suited to geothermal energy use. It includes electric power combined with process heat systems for large industrial users or the use of geothermal heat for feedwater heating in a fossil-fueled base station power plant.

A substantial fraction of the U.S. annual energy budget of about 80 quads produces heat used at temperatures below 20°C. Recent estimates indicate that over 25 percent, or about 20 quads per year, could be supplied by geothermal energy. Clearly, the extent to which this contribution occurs will depend in large part on the cost of geothermal heat versus the competition, particularly natural gas and oil. Principal issues affecting direct heat use include the following:

1. Distance between the geothermal resource and end user, which is critical to fluid distribution cost
2. Chemistry of the geothermal fluid, which may lead to corrosion and scaling of heat exchange surfaces
3. Quality of the resource in terms of temperature and depth.

APPENDIX D

GENERIC DEVELOPMENT NEEDS

UNCERTAINTIES IN LOCATING AND CHARACTERIZING RESERVOIRS

Characterization of liquid-dominated hydrothermal reservoirs is required to attract financial investment. Current methods of characterization are costly, and better and less costly technologies that embrace geology, geophysics, and geochemistry are needed to locate, delineate, characterize, and manage hydrothermal reservoirs.
Further technology refinements are required for: locating natural fracture systems and defining other relevant properties of reservoirs, matching the energy conversion process to be used to the reservoir characteristics, and forecasting reserves, including model verification of reservoir capacity and behavior under production conditions. The use of improved technologies for exploration is especially necessary in the case of "hidden" reservoirs that have no attendant surface manifestations.

HIGH DRILLING COSTS

High temperatures, hard rocks, and corrosive fluids raise geothermal drilling costs up to four times those for oil and gas wells at similar depths. These initial costs limit geothermal energy use for electric power generation and for many direct uses.

One of the more costly problems in geothermal drilling involves the loss of drilling fluid into fractured or highly permeable zones, thus interrupting circulation in the drilling fluid system. This interruption can account for up to 30 percent of the well cost. Other problems contributing to costs are maintaining borehole stability during drilling, completion, and production; the high cost of high-temperature drilling fluids; and the less-than-optimal speed and effectiveness of materials and equipment in penetrating hard rock.

CORROSION PREVENTION AND MATERIALS DURABILITY

Many geothermal waters leached from reservoir rocks contain dissolved solids and gases that corrode materials. Materials fail relatively quickly unless preventive measures are taken and corrosion-resistant materials are used.

Control of corrosion is better understood today, but much remains to be learned about the complex chemistry of fluids and their behavior under variable operating conditions. Research on corrosion prevention techniques is needed, especially in the following areas:

- Chemical corrosion inhibitors
- Cathodic and anodic protection
- Chemistry and kinetics
- Sampling and analysis.

Alternative cost-effective materials are needed to limit corrosion, enhance system performance, and reduce maintenance requirements. Research is needed on high-temperature elastomer formulations for dynamic seals and on fabrication and field-testing of elastomer-lined well casings. High thermal conductivity nonmetallic composite materials for heat exchanger tubing and metallic cladding for well casings are also needed.

LACK OF EFFICIENT COMPONENTS: DOWNHOLE PUMPS AND INSTRUMENTATION

Downhole pumping is an often useful or necessary adjunct to geothermal power plant development given moderate-temperature resources. It can increase flow, reduce solids precipitation, or maintain the brine in a liquid state for binary application. But submersible downhole electric pumps are not sufficiently reliable for economical use.

Historically, the major limitation of this technology has been thermal degradation of the motor and power cable by high temperatures and intrusion of the brine. Recent research and development have resulted in low-horsepower units that can survive and operate for a year in 80°C (175°F) brine, a performance that needs to be improved and extended to larger and hotter systems. One option is development of new metal-sheathed power cable, although efforts to upgrade pumps adapted from oil production may have already reached their limits. A wholly new design and approach may be needed. Deep well operation requires logging, that is, the measuring, recording, and evaluation of downhole conditions, especially in the geothermal environment.

Considerable work remains to improve or develop high-temperature downhole instrumentation. Specific areas of concern are discussed in Chapter 2 in the section on hydrothermal resources, including fracture detection and mapping devices, electric cables, fluid samplers, and logging tools.

INJECTION TECHNOLOGY FOR ECONOMIC DISPOSAL OF SPENT BRINES

Successful exploitation of a reservoir requires technology for disposing of large quantities of spent brines. Surface disposal is generally feasible only when the geothermal fluid is sufficiently pure to avoid adverse environmental consequences but it rarely is. This is rare. Otherwise, the fluid must be disposed of by subsurface injection.

If the spent fluid is not injected into the producing reservoir, the system may be depleted, resulting in insufficient fluid flow for operation or subsidence or both. Though injection recharges the system, short-circuiting of the fluid to the production zone before it reaches temperatures suitable for energy conversion must be avoided.

Fluid injection may result in precipitation of scale from the brine, blocking the flow paths and requiring either expensive workover or drilling a new well. Because dissolved solids from a given well vary, effective continuous monitoring instrumentation is needed, as are models to predict the degree of scaling under variable fluid conditions.

The technologies needed to ensure correct siting of injection wells to delineate flow and heat transfer mechanisms require R&D to improve geoscience techniques. In addition, further R&D is needed to improve the application of tracer methods for predicting and monitoring fluid migration.

CONVERSION TECHNOLOGY

Recent binary plant experience indicates that pump designers and fabricators have problems predicting the dynamic performance of working fluid pumps. Pumps are now based on suppliers' extensive experience in designing and fabricating water pumps. This experience cannot always be directly applied to pumps intended for service with other fluids. For example, liquid hydrocarbons are much more compressible than water. The lack of applicable pump design tools results in unexpected vibration problems and poor pump reliability.

A DOE target is to improve binary cycle efficiency by as much as one third over current advanced cycle technology such as two phase turbine expansion and a combined direct contact heat exchanger and crystallizer. Though direct contact exchangers do not appear to enjoy economic advantages over surface types for some applications, they may be the best hope under conditions of high scaling, an application that would be enhanced with the addition of a crystallizer. For binary technology to be successfully applied at lower temperatures (< 150°C [302°F]), even more advanced concepts, such as an ammonia cycle, need to be investigated.

Thus, work is required on the following:

- Improved performance cycles
    1. Two-phase expansion
    2. Direct contact heat exchanger and crystallizer
- Component improvement
    1. Hydrocarbon pump dynamics
    2. Brine production pumps
    3. Control systems.

APPENDIX E

BACKGROUND INFORMATION

HISTORICAL PERSPECTIVE ON THE GEOTHERMAL PROGRAM

Following a preliminary assessment of U.S. geothermal resources by the U.S. Geological Survey (USGS) and enactment of the Geothermal Steam Act in 1970, a 1971 legislative mandate established a geothermal program in the Atomic Energy Commission (AEC). The AEC program emphasized geothermal technology, and attempted to relate to industrial applications. About the same time, the National Science Foundation (NSF) considered geothermal energy in its Research Applied to National Needs project and thereafter became the lead agency for geothermal energy activities. The USGS, AEC, and NSF prepared the first coordinated federal geothermal energy plan in 1973.

In 1974, the Geothermal Energy Research, Development, and Demonstration Act created a national commitment to "dedicate the necessary financial resources and enlist the cooperation of the private and public sectors in developing geothermal resources . . ." The Energy Research and Development Administration (ERDA), created shortly thereafter, was given responsibility for implementing the R&D program. Implementation subsequently passed to the Department of Energy (DOE) when it was created in 1977.

A formal commercialization program was then initiated to promote early use of hydrothermal resources for both power generation and direct use. The commercialization program functioned for a time as a separate entity from the technology development division. From 1977 through 1981, the budget for the commercialization efforts was by far the largest element of the total geothermal energy budget. This budget embraced expenditures for the Baca, New Mexico, and Heber, California, cooperative power plant facilities; a program for direct use, resource assessment efforts by industry and some states; and studies on leasing, environmental, and other problems. This budget element remained high through 1983, reflecting the final federal outlays committed for the Heber plant. In 1981, however, a policy decision was made to rely on the market and on incentives of the National Energy Act of 1978 for geothermal energy commercialization. Emphasis shifted back to research and technology development (R&D), where it remains today. The budget history of the geothermal program from fiscal year 1976, when the Department of Energy (DOE) inherited it from ERDA, is shown in Table 2-1. A significant decline from nearly $158 million in 1979 to about $21 million in fiscal year 1987 occurred.

PRIVATE AND PUBLIC RESEARCH AND DEVELOPMENT EFFORTS

U.S. industry has been conducting geothermal energy R&D since its early exploration in the 1950s, almost entirely for hydrothermal resources. It also cooperates with DOE, as envisioned by the Geothermal Research, Development, and Demonstration Act, in cosponsoring R&D projects with the federal government. Other parts of the public sector, e.g., the U.S. Geological Survey (USGS), Bureau of Land Management, Forest Service, and state agencies, also participates in the DOE program.

As indicated above, industry exploration at The Geysers in California and at hot water fields in California and Nevada in the 1950s and 1960s predates the interest in the resource. It was during the 1970s that the government joined with industry during the 1970s to build a data base on promising hot water reservoirs and confirm the resource potential at selected sites through a government-industry cost-shared program.

Exploration has remained the exclusive purview of industry since then. The DOE contribution here and to related R&D areas is in continuing research to improve the technology base, enabling industry to develop advanced equipment and techniques for exploration, reservoir characterization, and reservoir engineering and management.

Industry has developed and perfected dry steam technologies used at The Geysers. For example, industry spent years and considerable funds developing cost-effective hydrogen sulfide abatement technologies. The government participated by developing and testing four alternative abatement methods.

R&D use of liquid-dominated resources for power generation in the United States date back to the experiments by San Diego Gas and Electric and Southern California Edison at the Salton Sea in California from 1972 through 1975. These experiments were followed in 1976 by the completion of the DOE Geothermal Loop Experimental Facility in the area, the first cooperative, jointly funded government-industry geothermal demonstration facility. Its purpose was to determine the technical and economic feasibility of generating electricity with highly saline brines. The most significant success of this venture was development of the reactor-clarifier brine treatment system, which, with more recent industry modifications, permits the use of these brines in several power plants today, opening development of a large geothermal resource at that site.

Industry R&D projects then included small geothermal power plants to demonstrate both the flash steam and binary technologies. Magma Power Company established a 10-MWe binary plant for using the relatively benign but moderate-temperature fluids produced at the East Mesa field in the Imperial Valley of California. Unocal and Southern California Edison were the principal participants in 10-MWe flash plants at the Brawley Reservoir

in Imperial Valley, where the brine salinity is only slightly less hostile than that at the Salton Sea, and subsequently at the Salton Sea geothermal field itself with salinities of 300,000 ppm (30 percent by weight).

Over the years, industry has spent at least $100 million to perfect the use of Imperial Valley saline geothermal brines. DOE and industry undertook to demonstrate commercial-scale power plants at Baca, New Mexico (flash), and Heber, California (binary). Production at Baca reservoir could not support the project, and although it was canceled, many valuable lessons were learned for future application. The 45-MWe (net) binary plant at Heber, designed as a demonstration plant to yield data for binary technology in general, is now in operation; it will provide data on the economics and operational viability of large-scale binary technology applicable to a wide range of moderate-temperature, low-salinity reservoirs. The data will also be applicable to small wellhead power plants. DOE has supported research on advanced binary technology, with emphasis on the application of direct contact heat exchangers.

DOE also supported development of technologies for direct use of energy from low-temperature geothermal fluids rather than its conversion to electricity. Under the Project Opportunity Notice Program of the late 1970s, DOE cost-shared 23 direct use projects with industry, municipalities, and institutions to demonstrate the technical and economic feasibility of a variety of applications. The program produced five successful and currently expanding district heating systems, six institutional space heating projects, a large commercial greenhouse, a 50-acre aquaculture project, and a cascade application combining agriculture and aquaculture.

Geothermal electric power production and most direct use applications require the production and disposal of large quantities of geothermal fluids. DOE R&D is attempting to ensure the technical efficiency, environmental safety, and cost effectiveness of reinjecting these fluids into the subsurface.

DOE and industry are conducting R&D to increase the fundamental knowledge of hydrothermal reservoirs through cost-shared drilling in the Cascades Range of the Pacific Northwest, which is believed to contain a large resource that is difficult to discover because of the effects of high levels of rainfall and snow on shallow subsurface temperature gradients. In addition, drilling for scientific data has been undertaken in the Salton Sea area in California, under the auspices of the Interagency Accord on Continental Scientific Drilling, to investigate a major hydrothermal system at greater depths than has been possible before. DOE, USGS, and NSF are signatory to the accord.

DOE is also conducting long-term R&D to develop technologies for extracting and utilizing geopressured geothermal brines and the heat of hot dry rock, and to determine the engineering feasibility of extracting energy directly from relatively shallow magma bodies. The fundamental data developed will allow industry to evaluate the commercial potential of these more difficult resources.

Privately funded industry R&D is highly fragmented due to the dissimilar elements in the industry. Given present energy markets and the limited private funding available for energy R&D, field development

efforts are limited, to a large extent to site-specific problem solving. Power plant operators, whether utilities or third party, are essentially at the same level of R&D. A Unocal/Southern California Edison partnership effected the first technology transfer from one plant to another in incorporating many of the technological breakthroughs achieved at the Brawley plant to the Salton Sea plant, permitting more efficient operation at the outset.

The Electric Power Research Institute has an active small geothermal R&D program. Similarly, the Gas Research Institute has a program on studying methane in geopressured brines. The geothermal R&D activities by EPRI include analyses of power systems, chemical analyses of the resource, and cooperation in experiments to generate electrical power.

The R&D conducted by equipment manufacturers and service-oriented companies is as diverse as the nature of the firms themselves, and developments in materials, components, and hardware systems are often supported wholly or in part by DOE. One notable exception is Schlumberger, whose entire company operation is based on its own R&D in well-logging technology.

The geothermal energy research activities of USGS are closely coordinated with those of DOE. When the USGS program directly supports specific DOE objectives, DOE provides funding to increase the timeliness of needed information. Most recently USGS is supporting the reservoir technology element of the DOE R&D program.

USGS, the Bureau of Land Management, and the Forest Service cooperated with DOE in a 1978 study on the effects of various provisions of Department of the Interior regulations (pursuant to the Geothermal Steam Act) on U.S. geothermal development. Improvements have been made in leasing and environmental study procedures in many areas, although some problems remain, as discussed in Chapter 2.

The State-Coupled Resource Assessment Program undertook to compile regional geothermal data on low- to moderate-temperature geothermal systems, to refine exploration target models, and to delineate optimal geothermal environments. Technical assistance to states for reservoir assessment is continuing on a limited and selected scale.

The results of federal, private, and public geothermal R&D are manifested in 16 operational hot water geoelectric plants, with a total capacity exceeding 215 MWe, over 60 MWe under construction in four plants, and more than 20 plants being planned. As of 1982, the hot water "industry" consisted of 33 MWe in four small demonstration plants. The success of private sector R&D is impressively represented by The Geysers geothermal complex, the largest in the world.

APPENDIX F

INVENTORY OF GEOTHERMAL POWER PLANTS

Tables F-1 through F-4 provide an inventory of geothermal power plants in the United States and the world.

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TABLE F-1 Geothermal Power Plants at The Geysers, California

Plant[a]	Year	MWe	Status
PG & E Geysers			
Unit 1	1960	11	Operational
Unit 2	1963	13	Operational
Unit 3	1967	27	Operational
Unit 4	1968	27	Operational
Unit 5-6	1971	2 x 53	Operational
Unit 7-8	1972	2 x 53	Operational
Unit 9-10	1973	2 x 53	Operational
Unit 11	1975	106	Operational
Unit 12	1979	106	Operational
Unit 13	1980	133	Operational
Unit 14	1980	109	Operational
Unit 15	1979	59	Operational
Unit 16	1985	113	Operational
Unit 17	1982	113	Operational
Unit 18	1983	113	Operational
Unit 19	n.a.	55	Preliminary planning
Unit 20	1985	113	Operational
Unit 21	1988	140	Advanced Planning
Unit 22	n.a.	140	Preliminary planning
Unit 23	n.a.	114	Preliminary planning
Unit 24	n.a.	114	Preliminary planning
Thermal-4 ("Wild Well")	n.a.	2	Preliminary planning
NCPA 2	1983	2 x 55	Operational
SMUDGEO No. 1	1983	72	Operational
Bottle Rock	1985	55	Operational
OXY 1	1984	80	Operational
NCPA 3:			
Unit 3	1985	55	Operational
Unit 4	1986	55	Operational
Modesto GEO	n.a.	110	Preliminary planning
South Geysers	--	55	Cancelled
SMUDGEO No. 2	1987	55	Preliminary planning
CCPA No. 1:			
Coldwater Creek	1988	2 x 65	Under construction
Total		1,788	Operational
		2,648	Operational, under construction, or planned

[a] All units are of the dry steam type.

SOURCE: DiPippo (1986).

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TABLE F-2 Geothermal Power Plants in the Imperial Valley, California

Plant	Year	Type	MWe	Status
East Mesa				
B.C. McCabe No. 1 (Magma)	1979	Binary	12.5	Operational
East Mesa No. 2 (GEO[a])	1988	2-flash	37.0	Under construction
East Mesa No. 3 (GEO[a])	1989	2-flash	37.0	Under construction
ORMESA I (Ormat)	1987	Binary	26 x 0.77	Operational
ORMESA II (Ormat)	1988	Binary	25 x 0.77	Under construction
Salton Sea				
Salton Sea (Unocal/SCE)	1982	1-flash	10.0	Operational
Salton Sea 3 (Unocal)	1988	2-flash	47.5	Under construction
Vulcan I (Magma/BMG)	1985	2-flash	39.6	Operational
Vulcan II (Magma/SCE)	1988	2-flash	39.9	Under construction
Vulcan III (Magma/SCE)	1988	2-flash	39.9	Under construction
Vulcan IV (Magma/SCE)	1989	2-flash	39.9	Under construction
Heber				
Binary demonstration plant	1985	Binary	45.0	Operational
Flash plant (HGC)	1985	2-flash	47.0	Operational
North Brawley				
Brawley (Unocal/SCE)	1980	1-flash	10.0	Decommissioned
Total			174.1	Operational
			394.7	Operational or under construction
			434.6	Operational, under construction, or planned

[a]Geothermal Resources International.

SOURCE: DiPippo (1986).

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TABLE F-3 Geothermal Power Plants in the United States (excluding The Geysers and the Imperial Valley)

State/Plant	Year	Type	MWe	Status
California				
Coso				
Unit 1 (Cal. Energy)	1987	1-flash	25.0	Under construction
Units 2-3	n.a.	1-flash	2 x 25.0	Advanced planning
Mammoth				
Mammoth-Pacific	1984	Binary	2 x 3.5	Operational
Chance Ranch (Wood & Associates)	1987	Binary	12 x 0.833	Advanced planning
Honey Lake	1987	Hybrid wood-geothermal	20.0	Under construction
Wendell Hot Springs				
Wineagle Project	1985	Binary	2 x 0.30	Operational
Hawaii				
Puna No. 1	1982	1-flash	3.0	Operational
Idaho				
Raft River	1982	Binary	5.0	Decommissioned 1982
Nevada				
Wabuska Hot Springs	1984	Binary	0.6	Operational
Beowawe	1985	2-flash	17.0	Operational
Brady Hot Springs				
Phase 1	1987	Binary	2.8	Under construction
Phase 2	1987	Binary	5.5	Under construction
Steamboat Springs	1986	Binary	7 x 0.77	Operational
Fish Lake	1986	Binary	15.0	Planned
Big Smokey Valley	1986	Flash (?)	10.0	Planned
Desert Peak	1985	Total flow/ 2-flash	9.0	Operational
Spring Creek	1987	2-flash	20.0	Planned
Dixie Central	1987	Flash	20.0	Planned
Oregon				
Hammersly Canyon				
Unit 1-3	1983	Binary	3 x 0.30	Operational
Unit 4-6	1984	Binary	3 x 0.37	Operational
Utah				
Milford				
Blundell Unit 1	1984	1-flash	20.0	Operational
Wellhead No. 1	n.a.	Total flow	14.5	Advanced planning
Cove Fort-Sulphurdale				
Phase 1	1985	Binary	4 x 0.675	Operational
Phase 2	1986	Binary	2 x 1.0	Advanced planning
Phase 2	n.a.	Dry steam	2.3	Advanced planning
Total			67.31	Operational[a]
			120.61	Operational or under construction
			264.40	Operational, under construction, or planned

[a]Includes plants under construction and scheduled for completion in 1986.

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TABLE F-4 Geothermal Power Plants on Line Worldwide as of 1986.

Country	Type of Power Plant: Dry Steam NPU[a]	Dry Steam MWe	1-Flash NPU	1-Flash MWe	2-Flash NPU	2-Flash MW	Binary NPU	Binary MWe	Totals NPU	Totals MWe
United States	26	1788	3	33	4	109.5	24	75.81	57	2006.31
Philippines	0	0	23	894	0	0	0	0	23	894.0
Mexico	2	10	7	165	5	470.0	0	0	14	645.0
Italy	41	499.7	1	4.5	0	0	0	0	42	504.2
Japan	1	22	6	88.1	2	105	0	0	9	215.1
New Zealand	0	0	1	10	9	157.2	0	0	10	167.2
El Salvador	0	0	2	60	1	35	0	0	3	95.0
Kenya	0	0	3	45	0	0	0	0	3	45.0
Iceland	0	0	4	11	1	28	0	0	5	39.0
Nicaragua	0	0	1	35	0	0	0	0	1	35.0
Indonesia	2	30.25	1	2	0	0	0	0	3	32.25
Turkey	0	0	1	20.6	0	0	0	0	1	20.6
China	0	0	6	4.866	3	9	6	0.7	15	14.586
Soviet Union	0	0	1	11	0	0	0	0	1	11.0
France (Guadeloupe)	0	0	1	0	1	4.2	0	0	1	4.2
Portugal (Azores)	0	0	0	3	0	0	0	0	1	3.0
Greece	0	0	1	2	0	0	0	0	1	2.0
Total	72	2349.95	62	1389.086	26	917.9	30	76.51	190	4733.446

[a]Number of power units.

SOURCE: DiPippo (1986).

APPENDIX G

RENEWABLE ENERGY PROGRAM REVIEW

OCTOBER 15-16, 1986

TUESDAY, OCTOBER 14, 1986

A tour of the Hot Dry Rock Project will be held this afternoon. Contact Mike Berger at (505) 667-3973, Los Alamos National Laboratory; if you want to take the tour, it will take about 4 hours.

7:00 - 9:00	Registration and informal reception Taos Room, Hilltop House Hotel	Michael E. Berger Phyllis J. Martell

WEDNESDAY, OCTOBER 15, 1986

7:30 - 7:45	Meeting participants meet at Hilltop House and are escorted by bus to TA-53, Building 1	Phyllis J. Martell
7:45 - 8:15	Registration	
8:15 - 8:20	Welcome	Director S.E. Hecker
8:20 - 8:40	Opening Remarks	Assistant Secretary Donna Fitzpatrick/ Dr. Thomas O'Hare/ Dr. Robert San Martin
8:40 - 8:45	Meeting Format Explanation	
8:45 - 9:15	Biofuels Overview	Donald Walter
9:15 - 9:45	Geothermal Overview	John Mock
9:45 - 9:55	Break	
9:55 - 11:30	Biofuels and Municipal Waste Program	
11:30- 11:40	Break	
11:40 - 1:15	Geothermal Technology Program	

Technical Host: Michael E. Berger

1:15 - 1:45	Travel to Otowi Building and Study Center	Phyllis J. Martell
1:45	Working lunch (by invitation only)	Phyllis J. Martell
1:45 - 6:00	Group Discussion Sessions (includes Working Lunch)	
	Biofuels: Growth Technologies, Sideroom A, Otowi Building	Wayne H. Smith, Panel Chairman
	Biofuels: Conversion Technologies, Sideroom B, Otowi Building	To be determined
	Geothermal: Hydrothermal Resources, Sideroom C, Otowi Building	Carel Otte, Panel Chairman
	Geothermal: Advanced Resources, Study Center, Room 222	Samuel Fleming, Panel Chairman
6:00 - 6:15	Break and walk to University House	Phyllis J. Martell
6:15 - 7:15	Reception (by invitation only)	
7:15 - 7:30	Walk to Otowi Building, Main Dining Room	Phyllis J. Martell
7:30 - 8:30	Dinner (by invitation only)	
8:30 - 8:45	Meeting participants returned to Hilltop House	Phyllis J. Martell

THURSDAY, OCTOBER 16, 1986

8:15 - 8:30	Meeting participants meet at Hilltop House and are escorted to Otowi Building and Study Center	Phyllis J. Martell

8:30 - 12:00	Discussion Session (continued) Prepare findings and chairpersons' summaries	
	Biofuels: Growth Technologies, Siderroom A, Otowi Building	Wayne H. Smith, Panel Chairman
	Biofuels: Conversion Technologies, Sideroom B, Otowi Building	To be determined
	Geothermal: Hydrothermal Resources, Sideroom C, Otowi Building	Carel Otte, Panel Chairman
	Geothermal: Advanced Resources, Study Center, Room 222	Samuel Fleming, Panel Chairman
12:00 - 12:05	Walk to Otowi Building, Main Dining Room	Phyllis J. Martell
12:05 - 12:45	Lunch, Main Dining Room	
12:45 - 1:00	Travel to TA-53, Building 1, Auditorium	Phyllis J. Martell
1:00 - 3:00	Presentations by Discussion Group Chairpersons (30 minutes each)	Wayne H. Smith, To be Determined, Carel Otte, and Samuel Fleming
3:00 - 3:45	Adjourn and return to Hilltop House	Phyllis J. Martell
3:15 - 4:15	DOE Executive Staff Review	All DOE Personnel
4:15 - 4:30	DOE personnel return to Hilltop House	Phyllis J. Martell

OCTOBER 17

A tour of the Hot Dry Rock Project will be held this morning. Contact Mike Berger at (505) 667-3973, Los Alamos National Laboratory, if you want to take the tour. It will take about 4 hours.

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GEOTHERMAL BRIEFING OUTLINE

October 15, 1986
Los Alamos National Laboratory

9:15 - 9:45	Introduction and overview	John Mock, DOE
HYDROTHERMAL RESOURCES PROGRAM		
11:40 - 11:45	Key issues	John Mock, DOE
11:45 - 12:05	Hydrothermal reservoir research	Clay Nichols, IDO
12:05 - 12:20	Hydrothermal drilling research	Dick Traeger, Sandia
ADVANCED RESOURCES PROGRAM		
12:20 - 12:40	Key issues geopressured resources R&D	James Bresee, DOE
12:40 - 1:00	Hot dry rock research	John Whatten, LANL
1:00 - 1:10	Magma energy research	Dick Traeger, Sandia
1:10 - 1:15	Key points and summary	John Mock, DOE

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BIOFUELS AND MUNICIPAL WASTE
BRIEFING OUTLINE

October 15, 1986
Los Alamos National Laboratory

8:45 - 9:15	Introduction and overview	Donald Walter, DOE
GROWTH TECHNOLOGIES		
9:55 - 10:25	Terrestrial	Robert Van Hook, ORNL
10:25 - 10:35	Aquatics	Stanley Bull, SERI
CONVERSION TECHNOLOGIES		
	Biochemical Conversion	
10:35 - 10:55	Liquid fuels	Stanley Bull, SERI
10:55 - 11:05	Gaseous fuels	Stanley Bull, SERI
	Thermochemical Conversion	
11:05 - 11:10	Municipal waste	Stanley Bull, SERI
11:10 - 11:25	Biofuels	Gary Schiefelbein, PNL
11:25 - 11:30	Key issues and summary	Donald Walter, DOE

APPENDIX H

UNIT CONVERSION TABLE

1 km	=	0.6 mile
1 quad	=	1 Tcf = 10^{15} Btu = 10^{12} scf
1 MW	=	10^{3} kW = 10^{6} W
1 GW	=	10^{3} MW
1 bbl	=	42 gal = 5.61 scf
^{o}F	=	9/5 ^{o}C + 32
1 bbl of oil	=	5.6 million Btu
10 mills	=	1 cent (U.S.)

bbl	=	barrel
GW	=	gigawatt
km	=	kilometers
MW	=	megawatt
MWe	=	megawatt electric
scf	=	standard cubic feet
Tcf	=	trillion cubic feet

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